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THE UNIVERSITY OF MISSOURI BULLETIN

Number 7
·ENGINEERING EXPERIMENT STATION
Volume 3 Number 1

THE USE OF METAL CONDUCTORS TO PROTECT BUILDINGS FROM LIGHTNING

BY

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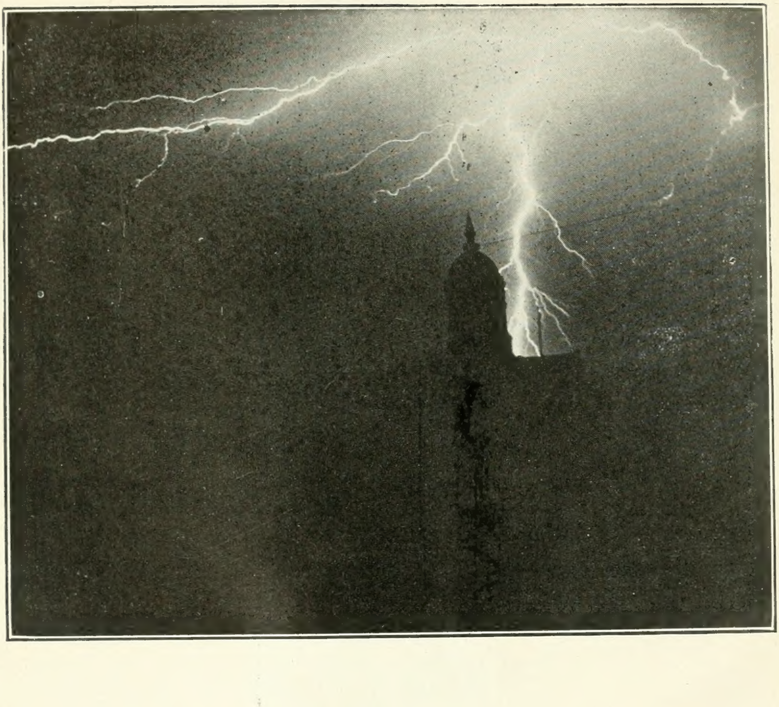
14. 4. 28.

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
March, 1912



INTRODUCTION.

There is a widespread popular belief that lightning-rods are of little or no value. Years may pass by without a single case of lightning stroke in a whole village or town of unrodded houses. On the other hand, one reads occasionally of a rodded building being struck and burned.

If rodded buildings are sometimes struck while thousands with no rods escape, what reason is there for supposing that rods give any protection?

It is clear that the rods do not give complete protection, but it may very well be that they reduce the danger of lightning stroke, giving a partial protection. Whether this is true or not can hardly be judged from the few cases that come to the attention of the individual. It must be tested by extended observations covering a great many buildings and a considerable period of time.

The reports of the Farmers' Mutual Fire Insurance Associations of Iowa and Missouri throw some light on this question. Delegates from the different counties meet each year in convention, and the question is asked:

"Did you have any losses from lightning on rodded buildings?"

The following table shows the experience in Missouri. The number of associations reporting no damage to rodded buildings gives an idea of the extent of the territory covered, while the heavy losses to other property caused by lightning, show that the lightning had by no means been idle, and the rodded buildings must have had plenty of chance to be struck. Nevertheless, during the three years there were only eleven cases of damage to rodded buildings in the State of Missouri, and in most of these cases the damage was slight:

	Number of Cases or Damage to Rodded Buildings.	Number of County Associations Reporting No Damage to Rodded Buildings.	TABLE NO. 1 Total Amount Paid Out for Losses from Lightning.
1909	1	Not stated in report	$29,755.23
1910	4	63	97,361.39
1911	6 none serious	62	91,678.95

The experience of the Iowa Farmers' Mutual Fire Insurance Association has been very much the same, only about one county in ten reported any cases of damage to rodded buildings, while nine counties out of ten had had some of their unrodded buildings struck and injured each year.

REPORTS OF THE IOWA FARMERS' MUTUAL FIRE INSURANCE ASSOCIATIONS.

Year.	Number of Associations Reporting Damage to Rodded Bldgs.	Number of Associations Reporting No Damage to Rodded Bldgs.	Number of Associations reporting Damage to Unrodded Bldgs.	Number of Associations reporting No Damage to Unrodded Bldgs.
1908	6	43	44	7
1909	3	36	42	3

In most of the cases of damage to buildings with rods the cause was found to be defective or incomplete rodding.

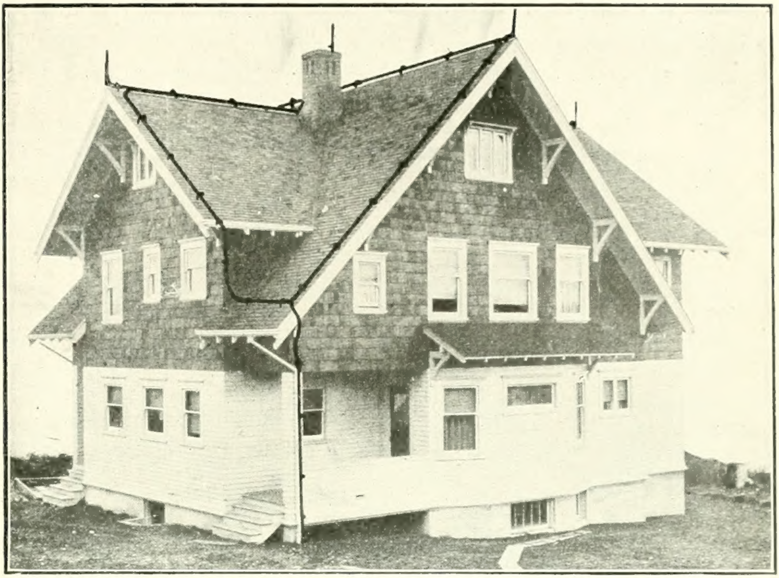
Still more instructive are the reports of amounts paid out by the Iowa Farmers' Mutual Fire Insurance Associations for damage by lightning.

FARMERS' MUTUAL FIRE INSURANCE ASSOCIATIONS OF IOWA.

Year.	Losses on Buildings and Contents Resulting from Lightning.	
	Buildings Rodded.	Buildings Not Rodded.
1908	$125.60	$46,010.22
1909	953.00	35,076.65
Total for 1908 and 1909.	$1,078.60	$81,076.87

These figures show that during these two years the unrodded buildings suffered nearly eighty times as much damage from lightning as those with rods. The total losses for four years, 1908 to 1911, show the unrodded buildings as suffering sixty times more heavily.

In order to arrive at a fair estimate of the protective value of the



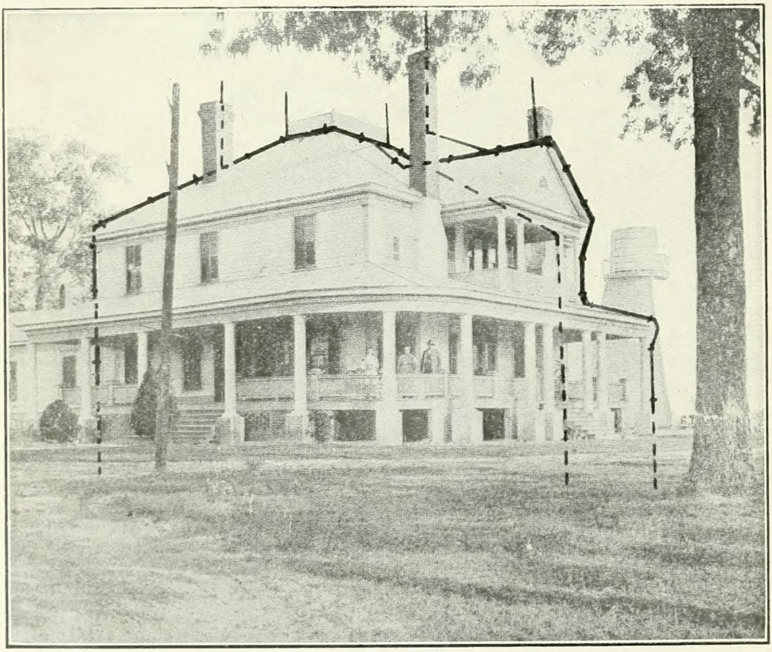
rods, it would be necessary to compare the damage that occurred to a given number of rodded buildings with the damage to an equal number of unrodded buildings during the same period of time. There are probably about four unrodded to one rodded building in the State of Iowa—we are speaking of the larger farm houses and barns. Therefore, we must divide the $180,000 total loss on unrodded buildings by four, which will give $4,500 as the damage suffered by unrodded buildings equal in number to those with rods. To illustrate, suppose that the insured farm buildings of the State numbered 100,000, of which 80,000 had no rods. The loss on the 20,000 rodded buildings amounted to $3,000, and the loss on the 80,000 that were without rods was $180,000. The loss on 20,000 of the unrodded buildings would have been one-fourth of $180,000, or $45,000, which is fifteen times as great as the damage suffered by 20,000 similar buildings that were provided with rods.

The conclusion from these figures, then, would be that rodding reduced the damage from lightning to something like one-fifteenth part of what it was without the rods; and this, it should be remembered, was the result, not of the best possible system of rodding, but of good rods and poor ones taken together.

The lightning rod, however, has not proved as useful in this country as it might, on account of ignorance of its true value, and on account of the fact that rods have frequently cost a good deal more than they needed to.

It is unwise to rod some buildings, and it is foolish to leave some others unrodded. In some cases the cheapest system possible should be used; in others a better and more expensive kind of rodding is justified.

It is the purpose of this bulletin to set forth in an impartial way and as simply and clearly as possible, such facts as will assist the reader first, to decide wisely whether or not to rod his building; secondly, to enable him to understand how lightning rods operate and how they should be constructed, and to compare the merits of different rods and rodding systems; thirdly, to give such directions that any one who wishes can buy the materials and place a satisfactory system of lightning conductors on his own buildings; and lastly, to offer some other suggestions in regard to safety from lightning, which may be of value.



HISTORY AND DEVELOPMENT OF THE USE OF LIGHTNING RODS.

It was Benjamin Franklin to whom the idea first occurred that lightning might be the same thing, only on a gigantic scale, as the electric sparks a few inches long that men had produced in laboratories. Although the two seemed so different, Franklin noticed that they had some remarkable points of similarity. Artificial electric sparks are like lightning in the peculiar crooked courses they take, their suddenness, the color of the light produced, and the odor that follows. Both produce noise, can kill animals, set fire to inflammable materials, rend bodies which they pass through, and are carried easily by metals, but sometimes melt the metal if it is not large enough.

Franklin's Experiment.—With these facts in mind Franklin devised a scheme to draw a small quantity of the electrical energy (if it should really prove to be electrical) from a storm cloud. On July 4, 1752, he succeeded in doing this with the help of a kite; and the sparks he drew from a key suspended at the lower end of the kite-string were exactly like those that he had produced in his laboratory. Thus he demonstrated to his own satisfaction, and to the satisfaction of the whole scientific world, that lightning and electricity are identical.

Invention of the Lightning Rod.—The first use Franklin made of his discovery was to devise a way of protecting buildings from lightning. Having been a student of electricity for a number of years, he knew at once what the method of protection should be. He announced his discovery to the public in the pamphlet called "Poor Richard's Almanac," of which he was publisher, in the following words:

"It has pleased God in his goodness to mankind, at length to discover to them the means of securing their habitations and other buildings from mischief by thunder and lightning. The method is this: Provide a small iron rod, which may be made of the iron rod used by nailors, but of such length that one end being three or four feet in the moist ground, the other may be six or eight feet above the highest part of the building. To the upper end of the rod fasten about a foot of brass wire, the size of a common knitting needle, sharpened to a fine point; the rod may be secured on the house by a few small staples. If the house or barn be long there may be a rod and point at each end, and a middling wire along the ridge from one to the other. A house thus furnished will not be damaged by lightning, it being attracted by the points, and passing through the metal into the ground, without hurting anything. Vessels also having a sharp pointed rod fixed to the top of their masts, with a wire from the foot of the rod reaching down around one of the shrouds to the water, will not be hurt by lightning."

Growth in the Use of Lightning Rods.—Franklin and his friends immediately set to work to induce their fellow countrymen to place lightning rods on their houses. They set the example by protecting their own houses with rods. It was not a great while before some of these were put to the test. Mr. West, a Philadelphia merchant, was one of the first to provide his house with the kind of rod that Franklin recommended. A thunder storm occurred soon after it was finished and lightning struck the point of the rod. The stroke was witnessed by a number of people, who reported that they had also seen a flash near the foot of the rod. The house was not injured. On hearing of the flash at the base of the rod, Franklin concluded that the lightning must have left the rod because its connection with the earth was poor. By digging down a few feet he found that he was right, for the rod only reached down five feet and the ground around it was perfectly dry. He also examined the brass point and found that it had melted and run down much like the grease on a candle. Afterwards the brass or copper points were made of heavier wire and there was little further trouble of this kind.

A few cases such as this, where heavy strokes of lightning left houses uninjured, were enough to convince people that these rods afforded real protection. Nevertheless, there was a great deal of opposition to them at first and their use spread rather slowly.

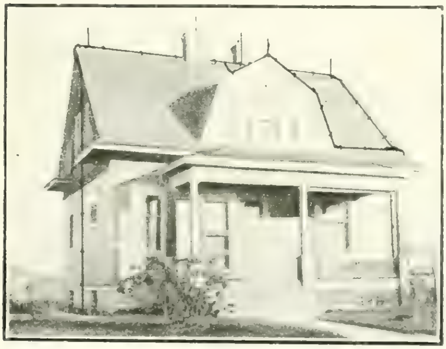
The Situation in America.—About a hundred years later, when the value of rods was conceded by every one, an unfortunate state of affairs arose in this country. Hosts of unscrupulous men, pretending to be experts, traveled through the land selling worthless rods at ten times what the material in them cost, imposing on ignorant people, and leaving in their trail rods that were so carelessly erected that they were as likely to be a source of danger as protection. The ability of a simple metal conductor to ward off danger of lightning seemed so wonderful and mysterious that it was easy to persuade people that some peculiar form of gilded ornamental tip, or a special shaped bar was the real secret of success of the particular rod the agent happened to be selling.

In a book on "Lightning Conductors" by Richard Anderson, published in London in 1885, the situation in this country was described about as follows:

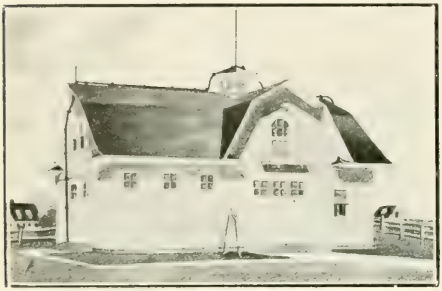
"America stands pre-eminent above all other countries in the numerous schemes that have been devised for the protection of buildings from the effects of lightning, and probably no other nation has been so systematically victimized and swindled in the matter. The tramping 'lightning-rod men' of the United States have been notorious for extortion and ignorance; they use all kinds of fantastic and peculiar shaped terminal rods and conductors, the main object apparently being to make as great a show with as little material as possible. Their work is almost entirely confined to the upper portion of the conductor, to the absolute neglect of the most important part—the earth terminal. The majority of the lightning conductors in America are consequently untrustworthy; very often they are practically insulated by the dry soil from the ground water, to which the lightning must find its way. They are therefore in such cases more a source of danger than a protection. Unhappily these traveling impostors are by no means extinct, although increased knowledge is gradually driving them out of the field."

It was natural that after such experiences as these, people should distrust all salesmen of lightning rods, and doubt whether any rods were of value. Lightning rods came to be regarded very much as "gold bricks," as a sign of ignorance on the part of the buyer. The man who bought a rod was ridiculed and the rod itself considered as a joke.

Fortunately a more healthy state of affairs in this respect is gradually coming about. In cities and towns there does not usually seem to be much need of lightning rods, but in the country there is still considerable destruction by lightning, and the rod is recognized as its true worth. Greater intelligence on the part of the farmer and reasonable caution enable him to buy what he needs in the way of a lightning-rod without being swindled. Besides the ignorant "frauds" who are still found occasionally, there are respectable companies making and selling lightning-rods, who know their business and do not make unwarranted claims for their rods. The best way to distinguish between the agent who represents a respectable firm and the "quack" is to learn as much as possible about lightning and lightning



protection by reading, and to compare the statements of a number of different companies before buying. One fairly good test is to find out how much pains the company takes in getting a good ground connection. This part is very important, and is hidden under ground. After the rod is in place no one knows whether the ground connection is good or bad. The representative of the firm which really seeks to protect the buildings of its customers will take great care to secure the best possible ground connection.



ELECTRICITY AND LIGHTNING.

Fundamental Facts About Electricity.—Electricity is a form of energy that shows itself in two different states—stored electricity and electricity in action or flowing.

Charges.—Electrical energy can be locked up or stored, and is then spoken of as an "Electric Charge."

Insulators.—In order that it may stay imprisoned it must be surrounded by some material through which it can not pass. Such materials are called "insulators" or "non-conductors," and a few of the most common of these are: air, glass, rubber, oil, marble and slate. Many other substances, such as paper, wood, sand, clay and stone are fairly good insulators, provided they are perfectly dry.

The following table gives some common materials arranged in order of their conducting power:

Good Conductors.	Poor Conductors.	Poor Insulators	Good Insulators
Copper	Solution of salt or lye	Porous stones	Dry gas or air
Aluminum	Dirty water	Dry earth	Varnish
Iron	Clean water & ice	Dry wood, leather or paper	Glass
Lead	Substances containing water, such as plants, animals and moist earth.	Oil and grease	Rubber
Other metals		Silk	Sulphur
Graphite		Paint	Mica
Charcoal and Coke		Dry sand	

Conductors.—There are other materials, however, through which the electricity can pass with more or less ease. Such materials are called "conductors."

By "good conductor" we mean one that offers very little obstruction or "resistance" to the passage of electricity. The other materials named as conductors show resistances hundreds or thousands of times greater than that of metals, but they may still be classed as conductors. Dirty or salty water is a much better conductor than pure water.

The word "conductor" is also used to designate any piece of conducting material, and it is frequently used here in the special sense of lightning rod.

Charges Reside in Conductors.—When charges of electricity are found they are nearly always in some body of conducting material that is surrounded by an insulator, such as a metal plate in air. In nature the stored electricity is in the cloud which consists of minute drops of water, and it is imprisoned by the surrounding air, which is an insulator.

Two Kinds of Electric Charges.—There are two kinds of charges, which are respectively called "positive" and "negative."* Taken by

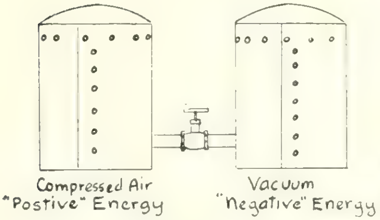


Fig. 1. When the valve is opened the two kinds of energy neutralize.

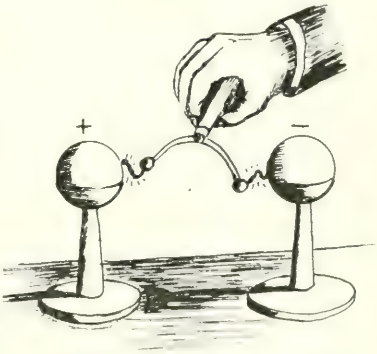


Fig. 2. Discharging a pair of charged conductors.

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*We might compare a positively and a negatively charged conductor to two tanks, one with air under pressure and the other with the air pumped out. Both tanks represent stored energy. We could attach a steam engine to the high pressure tank in place of a boiler and the engine would run. We could also run the engine for a few strokes by means of the vacuum tank by connecting the exhaust pipe of the engine to the tank and leaving the steam pipe open to the atmosphere. The air from outside would be drawn through the engine by suction and make it run. Hence we can say that the vacuum is just as truly stored energy as is the compressed air. Both tend to break the tank if it is weak, and both can be made to run the engine.

But if the two tanks were connected together by a pipe, the two kinds of energy would neutralize each other, just as the two charges of electricity neutralize.

themselves they are very much alike, and it is not easy to tell which is which; but they behave differently towards each other. A piece of material having a positive charge will repel another piece which is positively charged, and the same is true of two negative charges; but if one has a positive and the other a negative charge, they will attract each other. When a positively and a negatively charged body are placed near each other, not only do the bodies attract with considerable force, but the charges themselves get as near together as possible by concentrating in the parts of the charged bodies that are nearest together.

Discharge.—If now a wire is stretched across from one charged conductor to another, an electric current flows through the wire from the body that has the positive charge to the one that has the negative charge. After this passage has taken place there is no charge of any kind left. We say that the opposite charges have "neutralized" each other.

Breaking Through an Insulating Material.—Whenever there is a positive charge of electricity, there must also be a negative charge somewhere not far away. The one is never found without the other, and the electricity is trying to get across from the positively charged body to the other. If a cloud is carrying positive electricity, either the earth or else some other cloud is carrying a corresponding amount of negative electricity. If a wire or rod could be placed across from one to the other, the electricity would instantly make use of it to get across; but it does not wait for any wire, it "breaks" through the air that separates them, very much as the water in a pond may break through a dam. Whether it can do this or not depends on the distance it has to jump and the intensity of the charge, or in other words, the "electric pressure."

Electric Sparks and Lightning.—If electricity breaks through the air in this way on a small scale, it is an electric spark. If it occurs in nature between clouds or between a cloud and the earth, it is a lightning flash.

Electric Strain.—Just before it breaks down the air is said to be "electrically strained," for in some ways the behavior of an insulator seems like that of a piece of solid material which is strained and finally broken. After it has broken down, the air is really a conductor, although a rather poor one. When it has cooled off, it again becomes an insulator.

Value of Points.—Besides the discharge that occurs by the electricity breaking through the air, there is a perfectly quiet and harmless discharge that takes place more slowly, from any sharp edged or pointed conductors that reach up toward the cloud and are connected with the earth by a continuous line of conducting material.

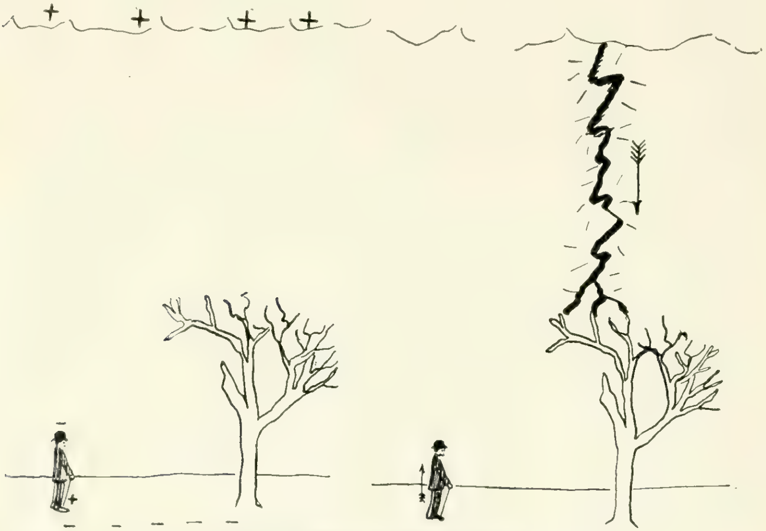
By neutralizing the charge in the cloud in this way a direct stroke of lightning may frequently be prevented. When a point is discharging electricity very rapidly, a faint blue haze appears right at the tip and there is a smell of ozone.

Where Lightning Occurs.—There are probably twenty lightning flashes between clouds to one between a cloud and the earth. The most frequent discharges occur near the front edge of the advancing storm. The places that are most likely to be struck are hill tops and other high objects, such as buildings. Lightning strokes are also more frequent in the neighborhood of bodies of water and over swamps. Where the earth is a good conductor there is more likelihood of lightning than where it is a poor conductor. For this reason moist soils and high ground-water level, as well as the presence of coal or iron ore tend to increase the danger of lightning. Smoke and some kinds of vapor seem to reduce the insulating power of the air, making lightning strokes more probable. The vapor from hay stacks and hay stored in barns appears to have this quality, as hay stacks are notorious for the frequency with which they are struck. A column of hot smoke is believed to form an easy path for a lightning discharge. But the smoke may have a beneficial effect, for the minute particles of soot carry away some of the charge from the earth and neutralize the charge in the cloud, accomplishing in this way the same valuable work as lightning rod points. So while a chimney may be more liable to stroke than surrounding objects of equal height, yet the fact that it is sending out smoke and hot air makes it less likely that there will be a stroke at all. The chimney protects its neighbors better than itself. This presence of numerous chimneys probably accounts to some extent for the small amount of damage from lightning in towns and cities.

Destructive Power of Lightning.—Wherever the lightning discharge goes it produces heat. The poorer the conductor through which it passes the greater the heat. A good metallic conductor of sufficient size will carry the current with comparatively little heating. It will get hot, to be sure, but not hot enough to do any harm. Now when lightning passes through stone and wood it develops great heat because they are poor conductors. If they contain moisture, it is instantly turned into steam and blows them to pieces. Wood is very likely to catch fire if it is dry enough to burn; and metal objects may be melted. When a flash passes from the air into a metal conductor, the conductor is apt to be melted at that point, but the heat which melts it is not produced in the metal, but in the air right next to it.

Shock from Lightning Without Being Struck.—People are very frequently knocked down or shocked when a flash of lightning occurs, and yet it appears afterwards that the lightning did not pass anywhere near them. It would not be unnatural in such a case to feel like accusing them of imagining their sensations, but the experience is not necessarily imaginary at all.

A lightning stroke always results in a sudden change in the electrical condition of the cloud. Usually the charge in the cloud is actually reversed a number of times in a very small fraction of a second. Suppose the cloud over a man is positively charged, and the earth is negative. Since the human body is a conductor, the positive charge in the cloud attracts a negative charge to the man's head, while the negative charge of the earth draws a positive charge to his feet. Now a lightning flash occurs somewhere near and in an instant the earth becomes positive and the cloud negative. The charges in the man will have to reverse at the same time, which means that a current of electricity passes from one end of his body to the other, and this is enough to give him a more or less violent shock.



Shock Without Being Struck.

Fig. 3. a. Just before stroke, + indicates the presence of a positive charge; — indicates the presence of a negative charge.

Fig. 3 b. During stroke. Arrow indicates the flow of electric current.

The Course Taken by a Lightning Stroke.—The course that a discharge will take is already practically determined before it occurs. Just before a flash between a cloud and the earth the air is under an "electric strain," and this strain is more intense in some places than others. The cloud is more highly charged at some points than at others, and as the mist condenses into rain the pressure keeps rising. The various objects on the earth are more or less charged and here and there are objects which are fairly good conductors. The distribution of electricity in the cloud, the presence of conductors and the presence of charged objects projecting above the earth all have a share in determining certain paths between the cloud and earth where the electric strain on the air is greatest. Then, the air is weaker along some lines than others, due to the presence of impurities and to moisture. These two factors together, intensity of strain and weak spots in the air, determine where the lightning strikes and what course it takes.

Does Lightning Strike Twice in the Same Place?—The saying that "lightning never strikes twice in the same place" is altogether wrong. Numerous examples are known of lightning striking the same place not only twice, but many times. In fact, a place that has been struck once is more likely to be struck again than a place which has never been struck. Of two similar houses, one of which has been struck and the other not, the one that has been struck is in greater danger during a storm, not because it has been struck, but because the same reasons that caused the lightning to select this house in the first place may still be present.

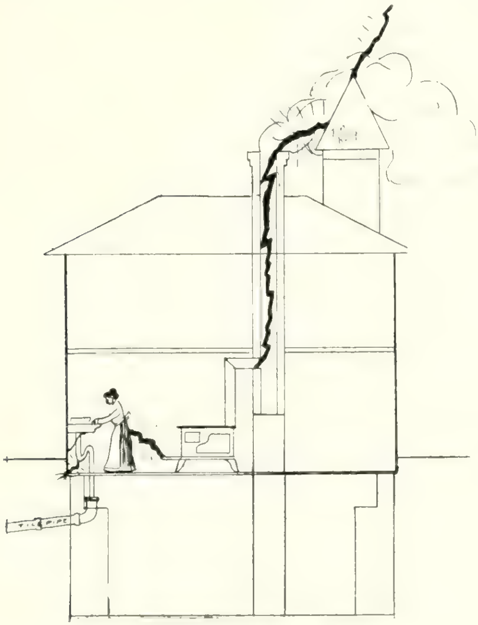


Fig. 4. Example of path taken by lightning.

Behavior of Lightning in a Building.—If lightning strikes a house that it not provided with a lightning conductor, its course is determined by what conductors it can find, by the electric charge on the various objects in its way, and by the insulating strength of the air and other materials that it has to break through. Usually it will be found after the stroke has passed that it has used any conductors that would help it on its way to the ground, jumping from one to the other when necessary at the point where they were closest together. For instance, it may strike a chimney, travel down the soot-covered inside, which is a fairly good conductor, along the stove pipe, through the stove, jump several feet through air to get to the sink, and pass down the drain-pipes to the earth. Another example, is a church, the steeple of which was struck. The lightning made use of a long iron rod used as a brace in the steeple structure. From the lower end of this it jumped to the clock works, which carried it as far as the clock face, where it jumped several feet to the lead flashing in a roof-valley. This lead flashing carried it to the roof gutter, which was metal, and the rain pipes took it to the ground.

If lightning strikes a lightning rod it will in all probability follow the rod into the ground, but if the ground connection is bad it is likely to take other paths. Even in the case of a good ground connection, it must be remembered that there is an enormous difference in electrical pressure between the top of the rod and the ground. This pressure may be sufficient to cause the lightning to jump from the rod to other conductors if there are any near, and send at least a part of the current that way. This is what is called a "side flash," and is of frequent occurrence. A good example of a side flash was a case when a man had a gun leaning against the wall in his house, directly opposite the lightning rod outside. The lightning passed through the wall to reach the gun, and from the butt of the gun struck through the floor to the ground.

Wherever the lightning can travel through metal, and the metal conductor is not so small as to be melted, no harm is done. Wherever it passes through other things it is likely to shatter them. Hence if there is any likelihood of lightning jumping from one metallic conductor to another, a good

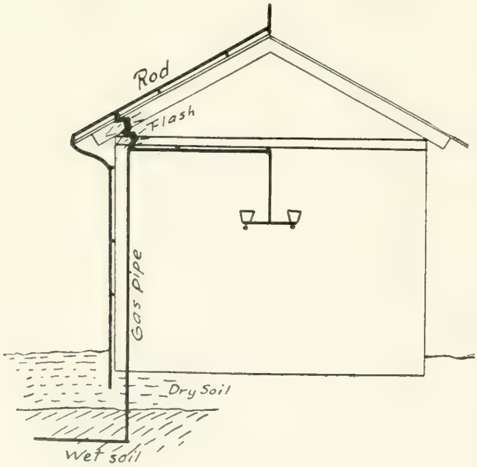


Fig. 5. Example of a side-flash.

metal connection should be provided so that the passage will not be attended by damage. Chains of conductors formed in this way must be complete all the way to the earth. For instance, if the roof gutter is connected to the rod it is still more important to provide a good ground connection from the bottoms of the rain spouts. Water and gas pipes have excellent connections with the ground, and if they pass anywhere near the lightning conductor they should be connected with it by metal. If the gas pipes are made of lead, however, they should kept well away from the lightning rod, as the lead may be melted even though there are good metallic connectors to it.

Lightning avoids roundabout paths whenever it can take a short cut, even though the short cut is of poor conductors and involves breaking through considerable air and other insulating materials.

In designing lightning conductors three things must be kept in mind:

1. Lightning is likely to make use of any metal that lies anywhere within reach and may do considerable damage in getting to and from this metal.

2. Lightning has a very strong tendency to split up and go part one way and part another. If the system of lightning conductors provided for it is arranged to permit it to do this, the danger of its taking other courses that were not intended is greatly reduced.

3. Lightning seeks as direct a path as possible. It might be compared to a man who is in a great hurry to get to a certain place. He prefers good roads if there are any, but will not go much out of his way for the sake of good roads, and even cuts 'cross-lots to save a little distance.

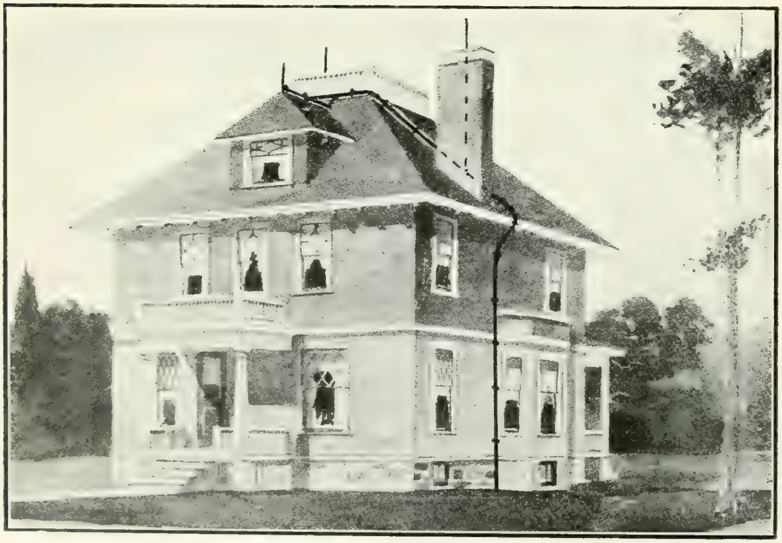
Again, it might be compared to a railroad passenger going to a distant city. If he can take a through train he will use it, but if any time is saved by going part way on one train and then changing cars, he will do that. The destination of the lightning is the ground. If a single continuous conductor will take it all the way, it will use that conductor, but if a more direct route is offered by several disconnected conductors, the lightning is apt to take the short cut, even if it has to make several jumps.

A rule adopted by the Royal Institute of British Architects is, that the length of a lightning conductor between any two points must not be more than one and one-half times the length of a straight line between these same points.

Resistance Not the Only Factor.—The great suddenness with which a lightning stroke occurs causes it to act very differently in a lightning rod from the way the electricity which supplies our electric lights would act. The dangerous "side flashes" that sometimes occur are because the electricity cannot get through the rod as fast as it wants to, and consequently finds other ways to get to the ground. But the trouble the lightning encounters in getting down the rod is not due to the "resistance" of the rod (which depends on the size of the rod and the material of which it is made) half so much as it is due to the difficulty of getting a big electric current started through the rod in so short a time. In this respect it is something like a gun. The tremendous pressure behind the bullet is not necessary merely in order to overcome the friction in the barrel, but to get the bullet started in a very short time.

For this reason the importance of using heavy copper rods, which give very low resistance, has been over estimated. So far as danger of side flashes is concerned, there is little choice between an iron wire 1-8 of an inch thick and a copper rod a half-inch in diameter. (There are, however, other advantages in favor of the large conductors, namely, less danger of their being melted, and longer life.)

The only real way to provide an easy path for the lightning and thus reduce the danger of side flashes, is to use several rods or wires connected together at the top so that the lightning can use all of them at once.



(See illustrations of rodded houses on pages 27 and 28 noting that wherever the lightning strikes it will find at least two ways to get to the ground.)

The farther apart these conductors are placed the better. Two wires twisted together are hardly better than a single one. An inch apart they are considerably better than one, a foot apart still better, and if twenty feet apart they offer hardly more than half the obstruction that a single wire would offer. Two wires placed twenty feet apart are better in this respect than twenty wires twisted into a cable. Three, four or five conductors may be used in this way to advantage, but it is essential that each one be provided with a good ground connection.

Only the Outside of the Conductor Is Used.—There is another effect which results from the great suddenness with which lightning comes on, and which is important in designing lightning conductors. Just as the electric current tends to split up and go down part one way and part another when there are several paths provided, so the minute streams that are flowing in a single rod or wire try to get as far apart as possible, with the result that all the electricity flows close to the surface of the conductor. If the latter is in the form of a round bar the current flows just in the "skin," if the bar is square the electricity crowds into the corners, or if in the form of a flat strip the two edges carry almost all of the current. If, instead of being a solid piece, the conductor is woven or twisted out of a number of smaller wires, the same thing holds true. The outside wires carry all, or nearly all, the current. If the conductor is so woven that the same wire is outside at one point and inside at another a slight advantage may be gained, but in general the current of electricity will cross from one wire to another so as to always keep on the outside.

Large Conductors Waste Material.—From this it is evident that the material in the interior of a conductor is wasted, is just so much dead "filler," and the larger the rod, the smaller the proportion of the material that actually does the work. Thus a very fine wire uses all its material, while a rod a half-inch in diameter would use less than a tenth of the material in it. A thin tube would serve just as well as a solid bar of the same size, so far as conducting the electricity goes, and tubes have been used, but they are frail and difficult to handle. Besides this, the metal in the interior, while it does not help conduct the electricity, does help to absorb the heat that is produced in the outer layers. Since the heat is produced so quickly that the air around the rod can not carry it away in time to prevent the rod from getting hot, this heat must be absorbed by the metal of the rod, and a certain amount of metal is necessary to absorb it.

A tube might melt, when a solid bar of the same size would be uninjured.

The only object then of using heavy conductors is to avoid the danger of their melting, and experience is the only guide in determining what sizes are necessary. But if instead of putting all the material into one conductor, several smaller ones are used, so that the current can split up and go part one way and part another, not only is the heat developed in each so reduced that there is less danger of melting, but a larger part of the material is useful in conducting the electricity, and a much easier path offered for the lightning to get to the ground.

Character of the Protection Afforded by Rods.—The protective power of lightning rods is three-fold; first, the preventive effect of the silent discharge from the points; secondly, that the rod, if an actual stroke occurs, will carry the lightning harmlessly to the ground; and in the third place there is less danger of persons or animals inside the building being injured by the shock (described on page 14) that is sometimes received by those who are not actually struck. The value of the points is universally conceded. They cause a gradual discharge that reduces the chances of a direct stroke occurring, though they can not always prevent a stroke. It takes time for the points to get in their work, and there are frequent cases where the conditions that cause a stroke come about so suddenly that no amount of pointed conductors would prevent it. Such a condition arises when the cloud over a building remains unchanged for some time and then is suddenly charged with electricity by a lightning flash between it and another cloud.

Examples of buildings struck in spite of pointed conductors are no argument against the points.

Do Lightning Rods Attract Lightning?—The question will naturally arise whether a conductor reaching up toward the cloud does not actually invite the lightning stroke. The answer is that it probably does to some extent. But it attracts the lightning only to itself. It can never in any case make the danger of some other part of the building being struck greater than without the rod. A number of cases are known in which

lightning had struck the rod and the people within the building had known nothing about it exceut that somewhere near by there had been a brilliant flash of lightning with loud thunder. The discovery next day that the points of the conductor has been fused showed what had happened. If the rod, however, is not such that it can take care of the discharge harmlessly when it is struck, it may be worse than nothing. But the question of whether the rod invites the lightning, makes a stroke more likely than before or not, is of minor importance. Experience has shown conclusively that it accomplishes its purpose, and that it is very rare indeed for a properly rodded building to be damaged by lightning.

LIGHTNING RODS AS INSURANCE.

Degree of Protection Afforded.—The question whether lightning rods afford protection was discussed in the introduction, and it was seen that the experience of the Farmers' Mutual Fire Insurance Companies indicates that rodding reduces the danger of lightning stroke to a small part of what it was before.

Wherever extended observations have been taken and accurate records kept the experience has been the same. In the province of Schleswig Holstein in Europe, rods are used very extensively, yet the records of fire insurance companies between the years 1870 and 1878 showed that while 552 buildings altogether were injured by lightning, only four cases were reported of injury to buildings that were provided with rods, and these rods were not in good condition.

If a building is equipped with a well designed system of lightning conductors the danger from lightning is so exceedingly remote that the claims of many lightning rod companies that "No building furnished with our rods has ever been injured," may very well be true. It may also be true that companies can afford to guarantee that no losses will occur on buildings which they equip with rods. It is to be doubted, however, whether such guarantees are in such a form that money could be legally collected from the companies in case of loss by lightning.

Extent of Damage from Lightning.—Having seen that danger may be reduced to practically nothing by good conductors, we may consider the question: "How serious is the danger without lightning conductors? Is the danger great enough to make it worth while to spend the money for conductors?"

These are the questions which are left to the judgment of the owner. He must decide according to his own feelings, his experience and observation of destruction in his vicinity, and such knowledge as he has in regard to the special conditions that make the danger to his buildings greater or less than to other buildings. A few facts are given here that may assist him in deciding the question wisely.

In cities and towns ordinary buildings are in so little danger that lightning rods are rarely installed. In villages the danger is greater; considerable damage is done in smaller towns, but not nearly so much as in the country. The isolated buildings on farms are by far the greatest sufferers from lightning. Some statistics have been gathered which seem to indicate that the danger from lightning is four to five times greater in the country than in the city.

The reports of the Farmers' Mutual Fire Insurance Companies of Missouri give the following figures of losses paid out during the three years, 1909 to 1911:

Year.	Total Losses.	Losses from Lightning.
1909	$237,202.38	$29,755.23
1910	281,726.37	97,361.39
1911	341,471.04	91,678.95
Total	$860,399.69	$218,795.57

From this it is seen that one-fourth of all the losses are due to lightning. The total cost of insurance comes to about 28 cents per year on every $100.00 worth of insured property. Since one-fourth of the losses are due to lightning, it would cost in the neighborhood of seven cents per year on every $100.00 worth of property, to insure against lightning alone.

This figure, however, does not correctly represent the risk to unrodded buildings. Seven cents per $100.00 is the cost of insuring rodded and unrodded buildings indiscriminately, whereas practically all the damage occurs to buildings without rods. Since the Farmers' Mutual Companies make no reduction in rates at present in favor of buildings protected by conductors, the rodded buildings are charged more than enough to pay for their own losses, while unrodded buildings pay less than the cost of their own insurance. If the unrodded buildings were charged a rate that would pay for their own losses, this rate would have to be considerably higher than seven cents per $100.00. It is impossible to say what proportion of the buildings insured had lightning rods. If 70% of the buildings insured were without rods, and had to pay a rate that would cover the cost of insuring them this rate would have to be 10 cents per $100.00 instead of 7 cents.

The figure, 10 cents per year for every $100.00 of building value, may perhaps be taken as a fair average of the risk to unrodded farm buildings throughout the State. To state it differently, there is one chance in a thousand that your unrodded building will be completely destroyed by lightning within the next year.

Based on this estimate you would be warranted in spending $1.00 a year to protect a building worth $1,000.00. Since $1.00 is the annual interest on about $20.00, it would be worth while to spend $20.00 on a lightning rod for a building worth (with its contents) $1,000.00, $40.00 on a $2,000.00 building, and so on.

Since the insurance companies make no difference in rates, it would seem at first sight that it would be better policy and cheaper to simply keep the building insured and let the insurance company take the risk. In some cases this is true, but there are many considerations that make it worth while to equip buildings with rods, even though it is a more expensive kind of insurance than that offered by insurance companies.

The Principle of Insurance.—The usefulness of insurance is based on the fact that a man can better afford to bear a slight loss that occurs regularly and that he can figure on, than to sustain a single heavy loss that he can not foresee. The small losses are to be sure, a drain on a man's resources, but a sudden great loss may rob him, not only of his property, but of his means of earning. A barn burned may mean not only the loss of the barn, but a crop ruined for lack of space to store it. Horses and tools missing when they are in greatest demand may mean heavy losses in the crop.

These things are not paid for by insurance companies, neither will they repay even the full value of the building itself and what was in it. Hence an additional insurance may be worth while.

So valuable is it to a man to eliminate chance, and to know beforehand exactly what expenses and losses he will have to meet, that it would pay him to insure his property even if the insurance company charged twice as much as it cost them. Fortunately this is not necessary, as insurance can be had nearly at cost. The less property a man has the more he needs to insure it. The millionaire can afford to be his own insurance company, but the farmer with a single house and barn can not.

Two Kinds of Insurance.—Insurance against losses may be had in two ways, either by spending some money in order to prevent the loss from occurring, or by contracting with an insurance company to have the company stand the loss if it does occur. The first kind of insurance might be call **preventive,** and the second **compensating.**

Preventive insurance may or may not be more expensive than the other, but it is more valuable. Compensating insurance never repays to the full extent of the damage, it **reduces** the loss to the individual, but does not prevent it. He still loses something and the losses that were not and could not be covered by the policy may be serious.

Insurance which pays for prevention, on the other hand, makes it unnecessary that the owner should bear any loss beyond the cost of the preventive measures. Besides this, there are things that can be insured by this method, for which the compensating insurance is altogether inadequate. A few thousand dollars is poor pay for the loss of a life. A life insurance policy will not take the place of a good doctor. Yet a wise man makes use of both. Many a house has been struck and some members of the family killed. Fire insurance companies do not repay those that are left for what they have lost, but lightning conductors might have prevented the loss.

Where Protection Is Most Needed.—To illustrate the cost of insurance against lightning we used the figure 10 cents per $100.00, or one chance in a thousand of complete destruction each year, but this estimate is an average for the entire State, and must not be taken as correct for all places. The danger may be much less in many places and may be five to ten times as great in others. Many counties showed averages twice as high as that for the State. The people living in a locality are perhaps the best judges of whether lightning damage there is unusually heavy or not. In hilly country thunderstorms seem to follow definite courses, so that certain places are visited by storms much more frequently than others. Storms are apt to travel along over valleys, over rivers and over lakes and swamps, in preference to other places, and for this reason buildings near such places are in greater danger. Buildings on hillsides and also large structures in the open country that stand out by themselves are especially likely to be struck by lightning. Barns in which large quantities of recently cut hay are stored are believed by many to be more in danger from lightning than at other times.

Large trees close to a house may or may not make the house safer than it would be without them. It is not wise to rely on them as affording much protection.

Summary.—To state briefly the considerations which determine what expenditure would be justified in equipping buildings with conductors, or whether they should be equipped at all, the following questions must be settled:

1. What is the chance of injury to the building?

2. Is it sufficient to insure it against lightning in a fire insurance company?

3. What losses might occur in case of lightning that would not be covered by the policy?

4. Does the building at some times of the year represent such a large part of your property that its destruction would be a very serious matter, ever though most of its value were paid you in cash?

5. Does your fire insurance company make any lower rates on buildings that are protected by rods?

6. Does the building contain persons or things whose loss could not be compensated for in money?

7. Would the personal satisfaction of knowing that your property was in no danger from lightning be worth more to you than simply to know that the loss would be refunded in cash?

It was seen that where storms are not unusually frequent lightning rods may be a somewhat more expensive form of insurance than the kind which insurance companies afford, and if the building is one whose loss would do no great harm beyond the cost of rebuilding, it would probably not pay to provide it with lightning conductors.

If, on the other hand, a lightning stroke would mean loss, either of life or property which would not be repaid by the cash value of the policy, the building ought to have both kinds of insurance—lightning conductors as well as fire insurance policy. This would be especially true of tall structures that are likely to be marks for the lightning, and of buildings situated in places where storms are frequent.

ARRANGEMENT OF CONDUCTORS.

In order to protect a building from lightning, lines of metal conductors must be run from the prominent points of the building, as directly as possible to the ground. Conductors should run along the roof ridges and up above the tops of cupolas and chimneys. If the roof is flat or has small pitch, conductors should be run along the eaves. Next to chimneys and cupolas the points most in danger are gable ends and dormer windows. The conductors on the roof must all be connected together and run down to the ground at several places, say at the corners, and buried deep enough to ensure an easy path for the discharge to get away into moist soil. If a metal roof is used it must be connected with the ground by wires and no further conductors are necessary except at chimneys, where a short rod should be run up a foot or so above the top, and should be soldered to the roofing at the bottom. Soldered joints must be so made that even if the solder were melted the parts would be held together otherwise, as by staples or wire.

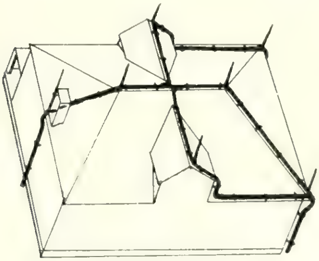
If the rain gutters are of metal they will serve as a conductor as long as they are in good condition. The tin rain spouts will carry the discharge toward the ground as far as they go, and a good connection must be made to them at the bottom, with conductors that run well into the ground.

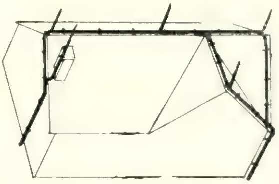
It is not uncommon to use sheet metal flashing along the hips and ridges of the roof and also in the valleys in order to insure a tight roof. If the lines of metal formed in this way are unbroken, they form in themselves a good system of lightning conductors, provided they are connected at their ends to rods running to the ground. It is best, however, not to let this flashing or the rain gutters and spouts take the place of rods, except on less exposed parts of the building.

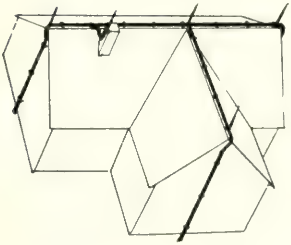
The tin roof of a cupola should be connected by several stout wires to the tin roof below, or if the main roof is of shingles or slate, a grounded rod should run direct to the cupola. Ornamental iron work on a roof should be connected to one or more rods leading to the ground.

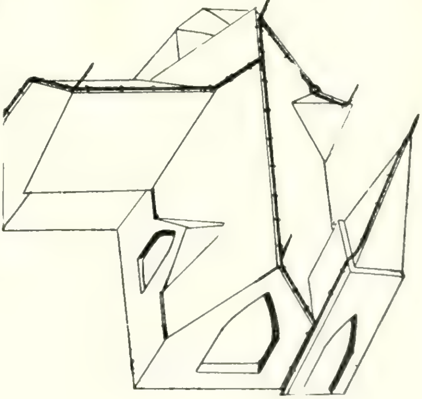
In short, all metal work on the roof, except very small pieces, should be made a part of the system by connecting it to the other conductors. The connection to any piece of metal should be at its lower edge or end.

Some illustrations are given showing good arrangements of rods for several styles of houses. The general idea is to cover the









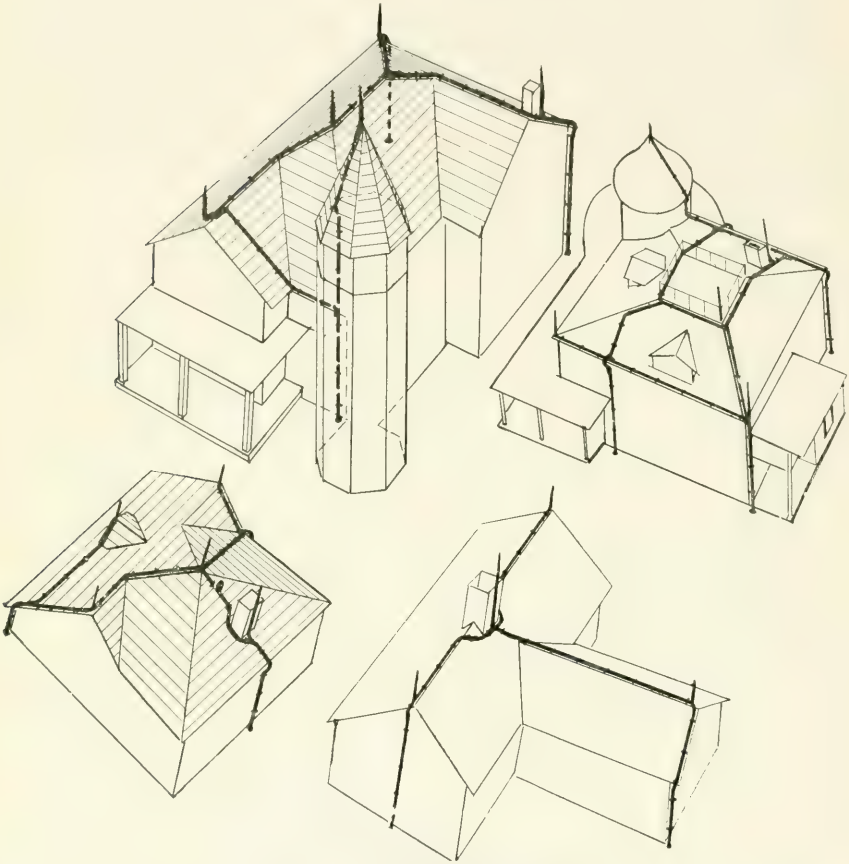


Fig. 7. Arrangements of Rods.

most exposed points in such a manner that from whatever angle a cloud should approach, the point on the building nearest the cloud would be covered by a conductor. It is also aimed to so connect the rods together that the lightning can find several paths to the ground at the same time; to get the verticals that lead to the ground well separated, and to have the paths to the ground as direct as possible. There are three factors which may make it necessary to modify any scheme of conductors:

1. All rods must be kept well away from gas pipes, especially

if the gas pipes are of lead.

2. Rain spouts or other conductors may take the place of some part of the lightning conductor system.

3. It may be necessary to arrange the conductors a little differently in order to reach and connect to other metal work on the roof.

Rodding a Tree.—Where a house is overtopped by a large tree, the rod may be placed on the tree instead of on the house. The rod in this case must be of as good material and just as carefully grounded as if it were on the house. It should run out one of the limbs that reaches over the house, but should be kept clear of the house by as much as ten feet if possible. The rod should not be attached too tightly to the tree, and should have a little slack, to allow for growth in the tree.

The Ground Connection.—The entire rod may be rendered useless by a poor ground connection, and for this reason great care should be taken with this important part of the system. The elec-

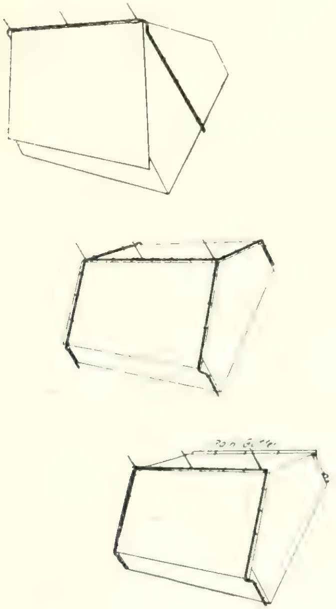


Fig. 8. A steep roofed building needs no conductors at the eaves. If the roof is flat, the eaves need protection, especially at the corners. The rain gutters may be sufficient protection for the eaves.

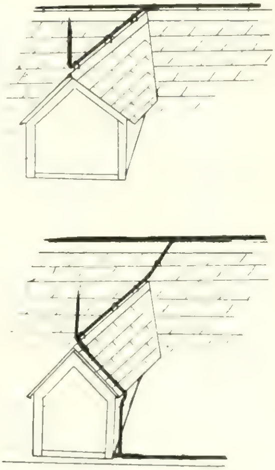


Fig. 9. If the ridge of a dormer or wing is short, and on the same level as the main ridge, it may be taken care of by a branch from the main line of conductor, as shown in the upper figure. But if it is below the level of the main ridge, or is more than about twelve feet long, a more direct path to the ground should be provided.

tricity must get to the ground water, or at least to wet soil. It can pass through moist soil, although this is a very poor conductor; but dry soil is such a good insulator that a lightning stroke on one occasion was known to travel 900 feet along a water pipe that was buried in dry soil, without being able to get away into the ground. The lightning reached the pipe in a house that was struck, went along the water pipe and did some damage to a drinking fountain 900 feet away.

You can not safely trust to luck that the ground will be moist four feet down. You must know from having dug down until you reached damp earth, and this ought to be done after a considerable period of dry weather. If you do not wish to wait for dry weather, and do not know what depth is necessary from previous observation, you should go deep enought to be on the safe side. In most places seven feet ought to be enough.

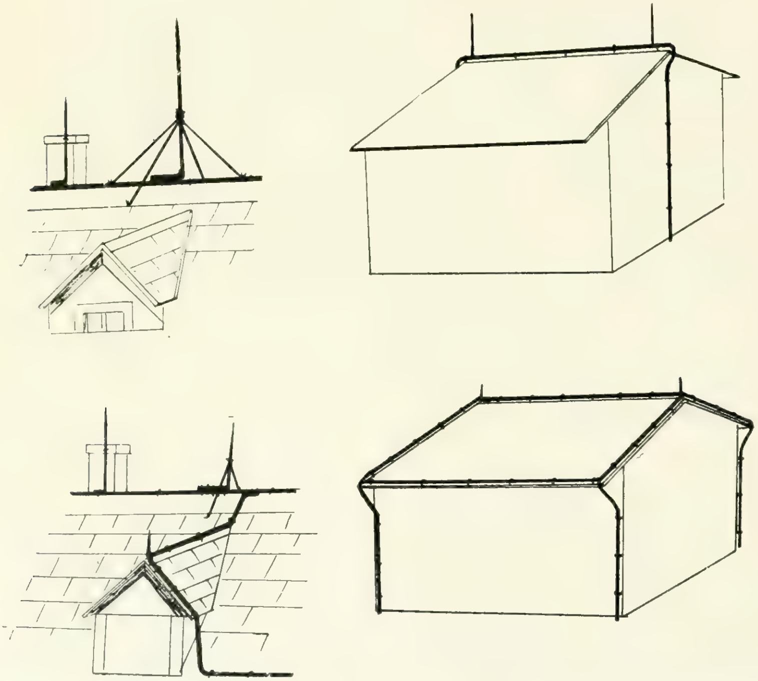


Fig. 10. It is largely a matter of choice and of appearance whether to use tall terminal rods, or to run extra lines of conductor to neighboring points that are somewhat exposed. But it is not well to rely on other near by rods to protect a chimney that is in use during warm weather.

Next in importance to reaching permanently moist earth is the problem of arranging the conductor so that the surface presented to the soil will be sufficient to allow the discharge to get away easily. The amount of surface of metal in contact with the soil is not the only thing to look out for. The electricity from the conductor must be able to spread out quickly into the soil. For instance there is no value in obtaining a large surface by burying a number of plates close together. The current flowing from one part of the conductor must not crowd the current coming from another part or from another conductor. For this reason two rods driven into the ground a foot apart are very much better than if driven six inches apart. A hole 18" square filled with coke is a very good ground connection, much better than that made by driving a 1½" galvanized iron pipe into the ground to the same depth; but two such pipes driven three feet apart and connected at the top are nearly as good as the hole full

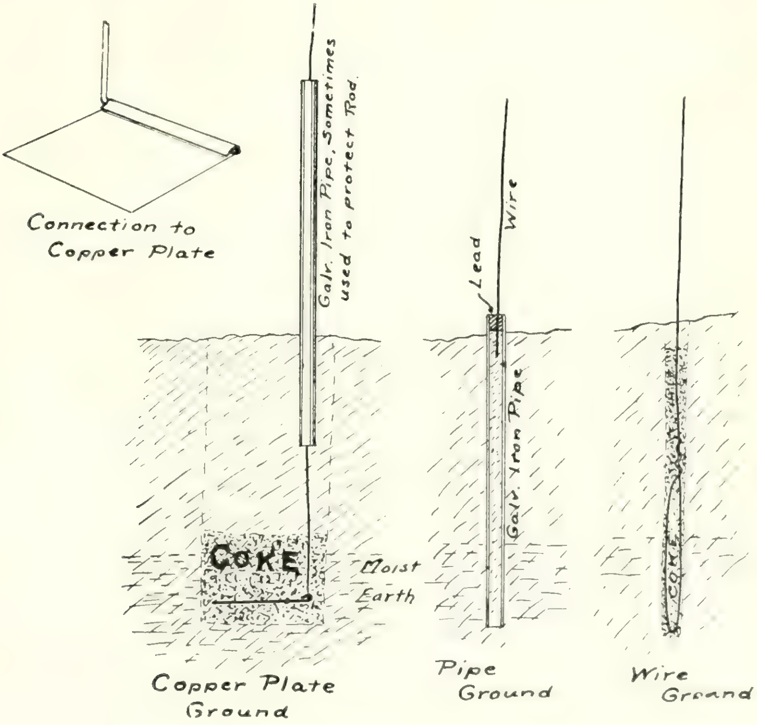


Fig. 11. Ground Connections.

of coke. Likewise the pipe is better than a wire 1-8 inch thick buried to the same depth; but two such wires six inches apart are as good as one pipe, although their actual surface is less.

All three kinds of ground connections have their places. The carefully made coke and copper plate ground is the safest and most permanent, and all large and important buildings should have at least one and preferably two ground connections of this kind or else a good connection to a water pipe. The other conductors on the same building may run to pipe grounds or to wire grounds.

Water Pipe Grounds.—This is the best of all ground connections and should always be used where there is a water pipe running to the building. A metal pipe from a well is as good as any water pipe if it is buried in the ground for some distance, but if it runs straight down the well without giving the lightning a chance to escape before it reaches the water, the well pipe should not be used.

Buried Plate.—Dig a hole 18 inches square and deep enough to get at least two feet below permanently moist earth. The wire that forms the lightning rod should be bent at right angles about 17 inches from the end. Cut a piece of sheet copper 17x18 inches and bend the edge over the wire so as to grip it tightly. The joint can then be heated with a blow-torch and solder run in. It would be well to use sheet copper as heavy as No. 22 gage, weighing about 14 oz. to the square foot for this purpose. Get about two bushels of charcoal or coke (the charcoal is preferable) and crush it sufficiently so that the powder and small lumps will fill up the spaces between the large lumps. Make a thin bed of the charcoal under the plate and put the rest on top. Pack the charcoal hard, and fill up the hole.

Instead of using a copper plate the wire itself may be coiled so as to present a large surface to the charcoal. The cost of such a ground should be about as follows:

Portion of rod below ground	$ .25
Copper plate	.50
Coke or charcoal	.25
Labor ..(Depends much on kind of soil and depth)..	1.00
	$2.00

Pipe Grounds.—Pipe grounds are neither as permanent nor as reliable as grounds made by burying copper plates in coke, but are sufficiently good for less important buildings or for some of the rods on a large building, if the most important rods of the building are furnished with copper plate grounds. By "most important" we mean the rods that come directly from the most exposed parts of the building.

Except in stony soil, one inch, to one and one-half inch galvanized iron pipe can usually be driven seven feet into the ground without great difficulty. If the soil is very sticky it may be easier to start the hole by driving a large pipe say three feet and then pulling it, and driving the smaller pipe the rest of the way.

To make the connection with the rod, insert the wire or rod a few inches into the top of the pipe. Fill the pipe with earth up to within an inch of the top and pour in melted solder or lead around the wire till it is flush with the top.

Care must be taken to protect the wire and place it where it will be secure from injury. It might in some cases be advisable to dig a hole and drive the pipe down until its top is a foot below the surface of the ground. The wire can then be run horizontally toward the wall and brought out of the ground right against the building where it will be secure. If there is any danger of any one's digging around it, the wire underground should be covered with a little concrete.

Pipe grounds ordinarily are very easy to make, but should not be relied on for more than about 10 years. The pipe will cost from 10 cents to fifteen cents a foot. On the average the cost might be:—

7 feet of pipe at 12cts.	$ .84
Labor	.30
Lead or solder	.05
	$1.19

Wire Grounds.—If a post hole auger is available or if the soil is such that a pipe can easily be driven and pulled out leaving a clean hole, wire grounds are the cheapest thing that can be used, and if carefully made should be nearly as good as pipe grounds. Since a good piece of copper wire as large as No. 6 B. & S. will last underground indefinitely, it is in this respect better than the galvanized pipe. The wire should be bent back to form a loop about 2½ feet long, the end being wrapped a few times around the main wire. Make the loop narrow enough to enter the hole easily, and be sure that it reaches the bottom. Fill in around the wire with powdered coke or charcoal and ram it down tight.

A ground of this kind will do for the less important rods on a large building or for any rod on a small building. It should cost not more than about 25 cents for the copper in the buried conductor (if No. 4 B. & S. wire is used) and about an hour's labor.

In Case of Rock.—In case a house is built where there is a ledge of rock a few feet below the surface of the ground, there is frequently some difficulty in getting a good ground connection. A water pipe connection should be used if possible. If a deep seam in the rock can be found make a ground connection in this. If necessary run the wire some distance in a trench to get to a good place for a ground connection. If nothing but solid rock can be found, dig a trench down to rock and some twenty feet long for each rod. Run a wire in a three inch layer of crushed charcoal or coke the full length of the trench.

Grounds Made Before the House Is Built.—If it is decided that a new house is to be rodded, figure out where the ground connection will come, before the foundations are put in. Run a No. 4 or No. 6 wire buried in crushed charcoal six feet along side of the footing in the bottom of the foundation trench and bring the wire up either outside or right through the concrete or masonry. The wire may continue inside the building all the way up to the eaves if desired, or it may be enclosed in the wall or buried in brick or stone work

Points or Terminal Rods.—If the rods run all the way up to all the prominent points of a building it is not necessary that they project above in the form of points if there is any serious objection to the points on the ground of appearance. If the points are omitted, conductors should run along all ridges and eaves, and to the top of each chimney where they should be attached by running a wire all around the chimney as close to the top as possible.

On most buildings, however, lightning rod points are not objectionable in appearance, they may be even decorative, and their presence adds to the security of the building by still further reducing the chance that lightning may strike anything but the rod. Besides this the points assist in preventing a lightning stroke from occuring at all. There is some difference of opinion as to the advantage of placing a number of sharp points on one terminal rod. The silent discharge from two points would be twice as great as from one point, if they did not interfere with each other, but the effectiveness of a point depends on its projecting above, and being kept away from other conductors. Hence is is doubtful if the advantage of placing a number of points together on a single rod is sufficient to justify the extra labor or expense.

The pointed terminal rods are ordinarily made from two to four feet high, and should be placed on all prominent points of the building and every 20 feet on long ridges. They should be made of copper and filed to a sharp point at the end. No. 3 B. & S. wire should be brought to a point in about 3-4 inch, No. 0 wire in 1 inch, and No. 0000 gage wire in 1 1-4 inches. The terminal rod needs to be of heavier material than the main conductor, first to secure stiffness, and secondly because it is more likely to be the part actually struck and hence is in more danger of being melted. "Hard drawn" wire should be obtained if possible for terminal rods since it is stiffer than the soft drawn, but the soft drawn wire is better for the main conductors. No. 2 or No. 3 wire may be used where it does not project more than ten or twelve inches above the last support. It might be used on such places as flag poles and chimneys.

No. 0 wire can be used where the rod does not project more

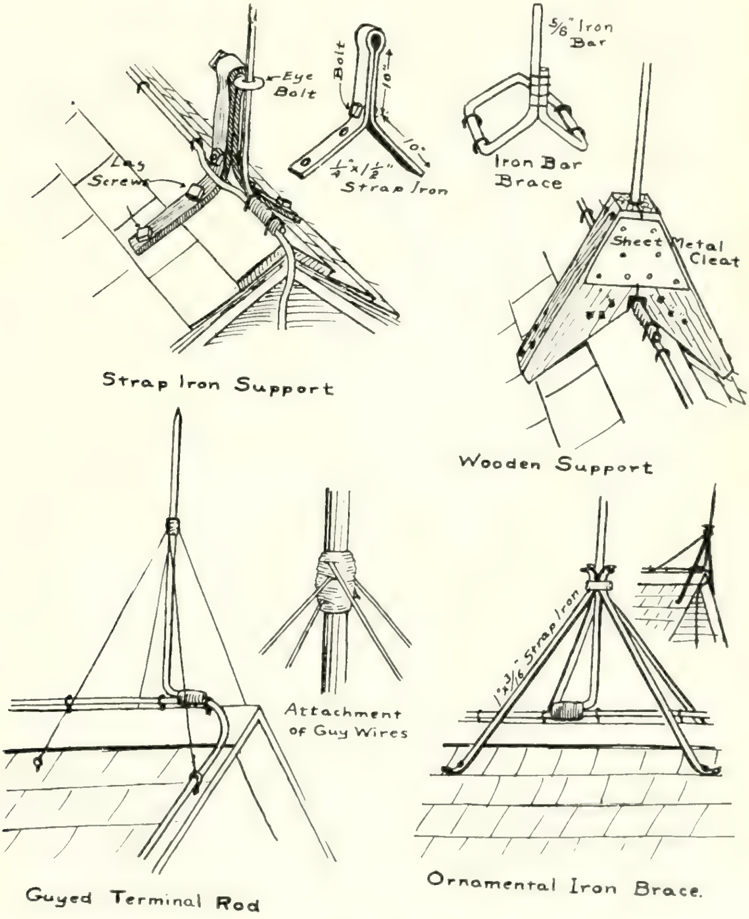


Fig. 12. Supports for Terminal Rods.

than 18 inches, and No. 0000 is stiff enough to stand about 24 inches above the last support.

Supports for Terminal Rods.—Several forms of supports are shown in Fig. 12. The strap iron support can be made up at a blacksmith shop and fastened to the roof with lag screws, care being taken to locate it directly over the rafters. It would be strong enough to support a rod four feet high.

The rod may be supported by wooden bracing. The only objection to the wooden support is the difficulty of giving it a good appearance.

If the terminal rod is fastened well at the bottom and braced by four guy wires, no further supports are necessary. A few small notches are filed in the rod about a foot from the top, or a small hole may be drilled and a pin put through. Two wires are wrapped tightly around the rod, above the pin or in the notches, leaving four ends three to five feet long as may be needed. No. 12 wire is a good size for the guy wires. The joint at the rod should be made more secure by wrapping a few turns of small wire on the outside, twisting the ends together and filling the whole joint with solder. The lower ends of the guy wires may be fastened with staples or screw eyes in the roof. This is probably the cheapest and strongest way of bracing terminal rods, especially the taller ones. The rod needs to be set back about a foot from the gable end if it is to be braced by guy wires. No. 0 wire would be heavy enough for rods braced in this way. Supports made especially for lightning rod terminals can be bought from dealers at a reasonable figure.

The Main Conductors.—The rods running from the terminals or points to the ground connections may be fastened to the building with large galvanized iron staples or with screw eyes. There is no object in insulating the rod from the building with glass or porcelain. There should be a fastening at every two and a half feet, on horizontal runs and every four feet on vertical runs. It is possible that a heavy lightning discharge might heat a small rod hot enough to set fire to woodwork. For this reason it is recommended that the rod be kept clear of wood in places where the wood is likely to be very dry and where a fire might gain considerable headway before being discovered. On the outside of the building, however, it is not usually considered necessary to keep the conductor away from the woodwork, since a fire from this source is very unlikely, and would probably be extinguished by rain if it should start.

If, however, the owner wishes to take every possible precaution, it is suggested either that he use a heavier conductor (say No. 2 or No. 3 B. & S. Copper wire) or else that he use some form of support which will hold the wire out from the wood work by about an inch, and that he place the supports not more than two feet apart. A few examples of suitable supports for this purpose are the double staple, porcelain cleat, and the screw eye.

Where appearance is not of prime importance, fasten the rod to woodwork with staples. Drive two staples side by side, one to hold the wire out from the building, and the other to fasten the wire, as shown in Fig. 13. The wire passes outside the first staple but under the second.

Porcelain cleats, such as are used for inside electric wiring, make very neat and satisfactory supports, but are more expensive

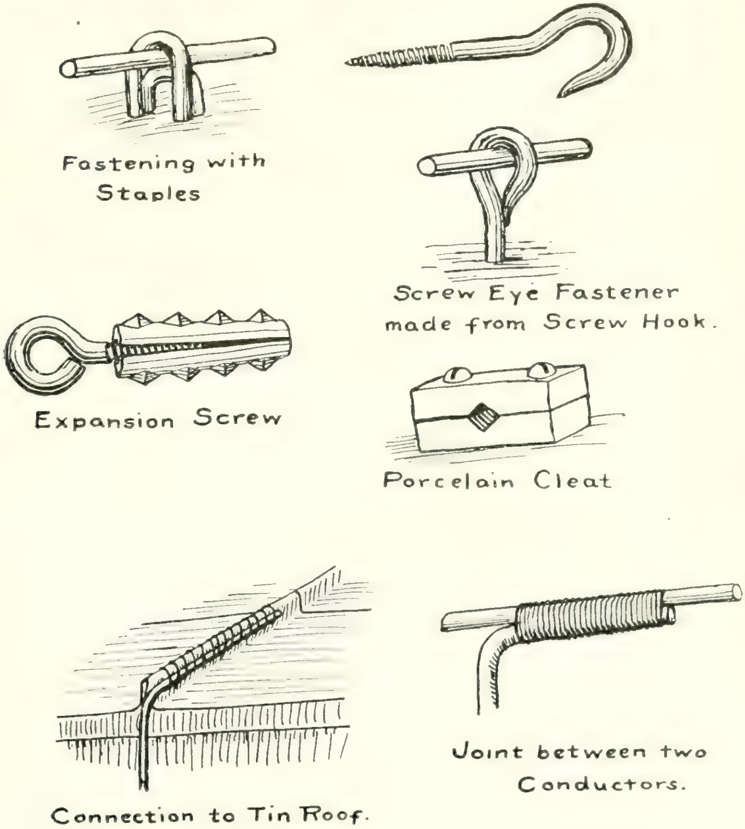


Fig. 13. Methods of attaching conductors to buildings.

than the other supports mentioned, costing in the neighborhood of $2.00 per hundred without screws.

Screw eyes are about as satisfactory in appearance as any support. Instead of buying screw eyes however, get No. 8 screw hooks (preferably brass) screw them in place, slip the wire under the hook and bend the hook shut around the wire. If regular screw-eyes are used they will either have to be screwed in place and the wire threaded through, which is likely to be difficult, or else the eyes may be bent open before putting them in place. Then the eye can be bent shut again around the wire as in the case of the screw-hook. Besides saving part of this labor, the screw-hooks have the advantage that they are made with longer shanks than the screw-eyes

Expansion eye-bolts are useful in fastening to brick or stone.

Rods may be run inside the building, or concealed in the wall if there is any good reason for doing so. The objection to enclosing them in a wall is that they are not open for inspection, and that a fire (if by any possibility one should be started) would not be discovered as promptly as if the rod were in the open. On the other hand the rod is protected from theft and from mechanical injury by enclosing it. The above objections do not apply to stone, brick or concrete walls. If a rod is to be placed within a wooden wall, it should be wrapped well with asbestos paper, and the paper securely fastened in place with wire, wherever the rod passes through a board, or where there is any possibility of its coming in contact with any wood. Here again the necessity of keeping the rod from touching wood, depends on the size of the conductor, but instead of using a large conductor for such places as inside a wall, where the rod is concealed, run an extra No. 4 conductor, parallel with the main line and wrapped about it at both ends, so that if either wire should be broken or cut the other would serve the purpose. The spare wire should be attached to the main conductor below ground, and should reach up above the place where the rod is concealed, and connected in again there. Another good arrangement is to box in the space where the rod is and fill up the form with concrete or else with dry sand.

It is usually necessary to take some care to protect a rod from theft. The copper is of some value, and the part of the rod near the ground is very easily cut and carried away. Painting the rod will help by making it less conspicuous. On stone or brick buildings it may be partly concealed by vines. The copper-clad wire, described later, has the advantage that it is very tough, and that its value as junk is almost nothing. The most common way of protecting copper rods from thieves, is to enclose the rod in a galvanized iron pipe reaching about two feet below ground and eight feet above. The pipe must be securely fastened to the building. Another way is to wrap the rod with asbestos paper and nail a grooved plank over it, running a spare wire alongside as described above. The rod may be run inside the wall, or a small form may be built around it and filled with concrete, first driving a number of stout nails or screws into the wall for the concrete to hold to.

In arranging the conductors avoid all sharp bends. Use long easy curves or "goose-necks" in going over the eaves, but if the overhang is considerable it is better to bore a hole and go straight through close to the wall. No joints should be used if they can possibly be avoided. The house should be measured before the material is ordered, and the order should give the lengths required, adding a few feet for good measure. Let the Supply House do the cutting if possible. Fasten the copper plate to one end of the wire and bury it in charcoal as already described. Without cutting the wire arrange it over the building as it is to go, and make the ground connection on the other end. Thus a single conductor should run from the buried copper plate at one corner of the building, up to the eaves, to the ridge, along the ridge to the other end and down to the other buried plate, without a single joint or splice.

Joints.—Where connection is made between two lines or rodding the joint should be made by wrapping the two together with smaller copper wire (say No. 19) and filling the cracks with solder. Be sure that all wires are clean and free from grease before attempting to solder. Treat the surface with acid used by tinners.

Material for Rods.—We have so far spoken of the conductors as "wire." Solid wire is about the cheapest form in which conductors can be had, and is easy to handle, and for this reason is the material usually preferred for home-made rods. There are other forms of conductors on the market, however, which are worthy of notice and which will be mentioned here.

The following table shows the sizes, weights and cost of a few sizes of wire that might be used.

Material.	Size B. & S. Gage.	Diameter Inches.	Weight per 100 ft.	Cost per Pound.	Cost per 100 ft.
Solid Copper Wire	19	.035	0.4	25c	$ .10
	12	.081	2.0	22	.44
	10	.102	3.1	22	.68
	8	.128	5.0	20	1.00
	6	.162	7.9	20	1.58
	4	.204	12.6	20	2.52
	3	.229	15.9	20	3.18
	2	.257	20.1	20	4.02
	1	.289	25.3	20	5.06
	0	.325	32	20	6.40
	00	.365	40.2	20	8.04
	000	.41	50.8	20	10.16
	0000	.46	64.0	20	12.80
Aluminum Wire	10	.102	1.0	45c	.45
	8	.128	1.5	45	.68
	6	.162	2.4	45	1.08
	4	.204	3.8	45	1.71
	2	.257	6.1	45	2.75
	4	.325	9.7	45	4.36
	0000	.46	19.4	45	8.75
Copper Clad Steel Wire 30% Conductivity	10	.102	2.9	16c	$ .46
	8	.128	4.5	16	.72
	6	.162	7.2	16	1.15
	4	.204	11.5	16	1.84
	2	.257	18.5	16	2.95
	0	.325	29.2	16	4.68
Galvanized Iron. Wire E. B. B.	Birmingham Gage No.				
	12	.105	3.1	5c	.15½
	10	.135	4.9	5	.24½
	8	.162	7.2	5	.36
	6	.192	10.2	5	[illegible]
	4	.225	13.8	5	.69
	3	.244	16.3	5	.82
	2	.263	18.9	5	.95

The above prices are approximate only, but will serve as a guide and to help in deciding what material to use. Copper changes considerably in price from month to month. Costs on special forms of lightning conductors will have to be obtained directly from the manufacturers.

Size of Conductor.—It has been the custom to use heavy copper conductors in order to avoid danger of their being melted, and also to reduce the danger of side flashes. The value of large conductors in respect to the latter point has been overestimated. The danger of melting and the mechanical strength of the rod are the principal points to consider. Records of melted rods are so few that it is impossible to say just what is the smallest size that will carry off a fairly heavy lightning discharge. No ordinary rod can be depended on not to melt at the point where it is struck, for the heat developed where the lightning passes from the air into the rod is very much greater than the heat developed in the rod itself. It seems probable that a No. 8 copper wire will conduct any ordinary lightning discharge without melting in two. This much is certain, even if a conductor should melt, it would have done its work before melting, so far as that stroke was concerned. As long as the conductor is there the lightning will pass through it. By the time it is melted a path is already formed and the electricity would continue to flow over the same course. There are cases on record of wires that directed strokes in this way, although the wires themselves had disappeared. This does not mean that it is well to employ a conductor that will melt, but it goes to show that even a conductor which melted during a heavy stroke would be better than none.

There are four ways in which too small a conductor is dangerous:

1. If it melts it may possibly cause the stroke to seek some other course which it would not if the rod had remained intact.
2. The great heat developed where the rod melted in two would increase the danger of fire.
3. If a second stroke should occur during the same storm, the house would be unprotected.
4. If the melting should not be noticed and the rod not repaired, the house would be unprotected in future storms.

It seems advisable to keep on the safe side by using conductors considerably heavier than that which is thought to be just sufficient not to melt.

In the arrangements of rods recommended in this bulletin there are (except for short distances) always two or three paths for lightning to get to ground. With such an arrangement it is believed that No. 6 copper wire would be safe, but in order to take no chances No. 4 is recommended for all the rods running to the most exposed parts of the building, while No. 6 might be used for cross connections and for conductors on places that are less in danger, such as eaves. It will be seen by consulting the table that the cost of No. 4 is only about $1.00 more per 100 feet than No. 6, and the amount saved by using the smaller wire for the main lines of conductor is not enough to make it wise to economize in this way.

If other copper conductor than the wire is used it should have at least as much weight per foot as the wire recommended here.

Other Materials for Rods.—Copper lightning rods have been made in many different shapes, such as square bar, fluted and twisted rods, flat strip, stranded cable, round woven cable, and flat woven cable. These forms have some advantages, but usually increase the cost more than they increase the efficiency of the rod.

There is no special virtue in any particular form of rod. Lightning does not travel better in a spiral. The only laws that lightning follows that have any thing to do with the shape of the conductor, are the laws that have been already stated in regard to the tendency to concentrate at the surface or edges or corners of a conductor. (See Page 19). The only purpose in making a rod any other shape than round, is to economize copper, and perhaps to make a conductor that is more easily installed.

A comparison will be made between a copper wire rod and some of the other forms, assuming that they all contain the same amount of copper per foot. Flat copper strip can be obtained from some electric companies and wire manufacturers.. It offers somewhat less resistance to the electric current than a round wire of the same weight, but is no better in this respect than two smaller wires placed an inch or two apart running parallel. The strip is somewhat more easily damaged than the round wire, and is awkward to install in some places.

Square or fluted rods, twisted or plain, have very slight advantage over round wire, and are hard to make good connections and joints with.

Copper wire rope or cable is somewhat easier to handle in larger sizes than solid bars of the same weight. For sizes less than No. 0 this advantage does not amount to much as the bar is not very stiff. Conductors made up of small strands are probably somewhat more easily melted than solid bars of the same weight. The theory that the extra surface exposed to the air will help keep the cables cool would be correct if the heating were slow and continued, but when it is all over in less than a second the circulating air has not time to do much good.

Woven copper cable both in the round form and flat, are made expressly for lightning conductors. They have no very great advantage electrically over other forms, but they are easily handled, and lend themselves readily to making joints, where joints are necessary.

Copper Clad Steel Wire.—A wire is made for some electrical purposes consisting of a steel wire with a covering of copper. A heavy copper tube is placed over a steel bar and the two welded together, rolled and drawn out into wire. This results in a wire with a very much thicker coat of copper than would be given by plating the steel with copper. It is made with various proportions of copper and steel. The kind known as "30 per cent Conductivity" is suitable for lightning conductors, and may be used in place of the solid copper wire for the larger sizes. For sizes less than No. 4 the saving is not enough to make it worth while. Since all the current flows close to the surface of the lightning rod a No. 4 copper clad wire will carry it as easily as a No. 4 solid wire. The copper clad wire costs four-fifths as much as the solid copper wire of the same size. It is very stiff, but this is not a serious objection, as sharp bends are always to be avoided. The principal objection to this material is the possibility of the copper covering being injured and the steel rusted through. It is doubtful whether it would last as well underground as solid wire, but above ground it should prove as durable as the solid. It will not do for terminal rods or points. In buying copper clad wire care must be taken to distinguish it from copper plated wire which is much cheaper and not suitable for this purpose. The copper clad will be seen by cutting to have a substantial covering of copper amounting to about one-sixth of the total amount of metal in the wire.

The following companies handling copper clad wire have come to the writer's attention:

Duplex Metals Co., Chester, Pa.
J. A. Roebling's Sons, Trenton, N. J.
Western Electric Co., Chicago, Ill.
Standard Underground Cable Co., Pittsburg, Pa.

Aluminum.—Aluminum wire can be obtained from companies handling wire for electrical purposes. An aluminum rod needs to be two or three sizes larger B. & S. gage than a copper wire for the same purpose. There will be little difference in the cost, and there is little choice between the two materials. Solder can not be used on aluminum, but merely placing the wires together and wrapping well with small aluminum wire results in a very good joint. Aluminum will last as long as copper, whether underground or over head, except near salt water, where it corrodes. Aluminum may be used to advantage for terminal rods instead of copper, since the same sized wire is lighter and just as stiff and costs less. There would be little economy in using aluminum points with copper rods, unless the same company handled both kinds of wire, as the extra freight or express would probably cost more than the saving.

Galvanized Iron Wire.—This is the cheapest material that can be used for lightning rods and is fairly satisfactory while it lasts. The best grades on the market (known as E. B. B. double galvanized) should be used. It would be well to use somewhat larger sizes than are required for copper rods, say No. 2 B. W. G. for the more important lines and No. 4 for the less important. Although more heat is developed in an iron rod than in copper, the iron is much harder to melt, so in this respect it is about as safe as the copper. The objection to galvanized iron conductors is that they will not last as well as the copper. Near railroads or factories or near the sea galvanized iron wire lasts but a short time, but in the inland where the air is pure it should last from 15 to 25 years. If used for terminal rods

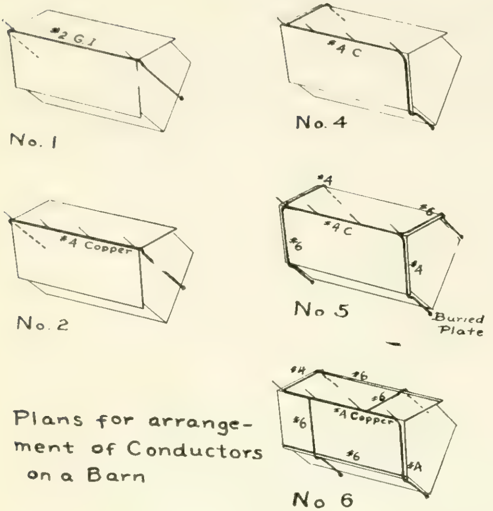


Fig. 14.

the points will rust blunt before a great while, and for this reason some other material is to be preferred. A short piece of copper wire, pointed, may be attached to the end of the galvanized iron terminal rod. The iron wire cannot be trusted underground for any length of time, hence pipe grounds would naturally be used in connection with iron rods, or else the iron wire may be joined to a copper or aluminum wire just above the surface of the ground. Joints should be made by wrapping with small copper wire and soldering.

Galvanized iron rods should be kept well painted.

Cost of Rodding a Barn.—In order to compare the different possible ways of rodding a building we shall take as an example a simple barn forty feet wide, sixty feet long, height of ridge above ground forty feet, height of eaves above ground twenty feet, distance from eaves to ridge twenty-nine feet.

The simpler arrangements outlined below will give fair protection, while the more elaborate arrangements will give greater security. For example, while plans No. 1 and No. 2 might reduce the danger from lightning to something like one-tenth part of what it would be without rods, plans Nos. 6, 7 and 8 would reduce the chance of damage to perhaps one-fiftieth part of what it was before.

Plan No. 1. Iron rod along the ridge only. Two points.

150 feet of No. 2 B. W. G. galvanized iron wire	$1.50
2 galvanized iron pipe ground connections	2.40
2 terminal rods with supports	2.00
Labor—placing conductor on barn	1.50
	$7.40

Plan No. 2. Same arrangement, but using No. 4 copper wire. One buried plate ground and one wire ground connection.

165 feet of No. 4 copper wire	$ 4.20
2 terminal rods with supports	2.00
1 buried plate ground	2.00
1 wire ground	.50
Labor—¾ day	1.50
	$10.20

Plan No. 3. Same as No. 2, but with four terminal rods......$12.20

Plan No. 4. Same as No. 3, but rods running over to the corners of the barn instead of straight down from the ridge. See illustration, Fig. 14.

This arrangement is frequently made necessary by doors in the ends of the building that interfere with running the rod down the face of the end wall. If the roof has less pitch than that given here (rise equal to one-half the span) plan No. 5 is decidedly recommended in place of No. 4. In any case No. 5 will give better protection. No. 4 exceeds the cost of No. 3 by 18 feet of No. 4 copper wire, costing 45 cents.

Plan No. 5. Rods running from the ridge to all four corners. No. 4 wire running all the way from one corner to the opposite corner. Branches to the other corners of No. 6 copper wire. Four terminal rods on ridge. One buried plate ground. Three wire grounds:

185 feet of No. 4 copper wire	$ 4.68
115 feet of No. 6 copper wire	1.82
4 terminal rods	4.00
1 copper plate ground connection	2.00
3 wire ground connections	1.50
Labor—placing conductor on building	3.00
	$17.00

Plan No. 6 same as No. 5, but a line of No. 6 copper wire run along the eaves of the roof.

120 feet of No. 6 wire	$ 1.90
Extra labor	.50
Other items as in No. 5	17.00
	$19.40

It would be well to run the lines of No. 6 wire that lead from the ridge to the ground about 15 feet back from the ends of the roof, thus providing a shorter path to ground for a lightning discharge that strikes the ridge near the middle.

This plan is advisable for a building with less pitch to the roof than the one described here. For buildings longer than 60 feet extra rods from the ground to the ridge should be placed on the side of the building.

Plan No. 7. Same as No. 6, but using two buried plate grounds at opposite corners and two wire ground connections. Estimated cost, $21.00.

Plan No. 8. Same as No. 6, but using three pipe grounds and one buried plate ground, and No. 2 and No. 4 galvanized iron conductor.

185 feet of No. 2 galvanized iron wire	$ 1.75
235 feet of No. 4 galvanized iron wire	1.65
4 terminal rods	4.00
1 buried plate ground connection	2.00
3 pipe ground connections	3.60
Labor—placing conductor on building	3.50
	$16.50

About $5.00 is saved by using iron instead of copper on a barn of this size covered with conductors as described in Plans Nos. 6, 7 and 8.

In addition to the materials named above, there would be required a half pound of No. 19 copper wire, one to three pounds of solder, some tinner's acid, some staples or screw hooks, coke or charcoal and copper plate, or galvanized iron pipe with some extra lead or solder for the ground connections.

The tools needed would be a post hole scoop or auger, gasoline torch, file or hacksaw, large pliers, sledge hammer or mallet for driving pipe, and carpenter's hammer.

Contract With Lightning Rod Companies.—As compared with the systems of rods installed by the owner, there are advantages in turning the job over to a company making a specialty of lightning rods. The completed work will very likely have a much more pleasing appearance if done by a lightning rod firm.

In the matter of safety, it would be money well invested to pay for expert advice, but it should be remembered that the real skill and knowledge is required, not for deciding what form of conductor or point to use, but in arranging the conductors on the buildings to secure the best protection with least expense, and in judging as to what depth and kind of ground connection is necessary.

The advantages of various forms of conductors have been discussed in this bulletin and there is little else to be said on this subject.

It is very difficult on the other hand to lay down rules as to the best places to run the rods and how to take care of other metal work in the house, because the conditions are different in every case. Each building is a problem by itself. It is here that trained judgment is valuable.

There are two ways a lightning rod company may furnish expert knowledge to its customers.

1. It may employ a man to devote his entire attention to this business, to visit the places of prospective customers, find all about the local conditions and lay out the plans for rodding.

The trouble with this plan is that the customer can not always tell whether the visitor is a real expert or not.

2. The company may give the agency for its rods to a local hardware dealer, tinner or plumber, requiring the local agent to send to the company complete plans and sketches of the building, showing the location of all metal work in or on the building, and notes on the character and moisture of the soil. With this information at their command, the company is in a position to give intelligent advice and can submit its plans and estimates to the customer. With any less information than this, any claim to giving expert advice is a mere pretense.

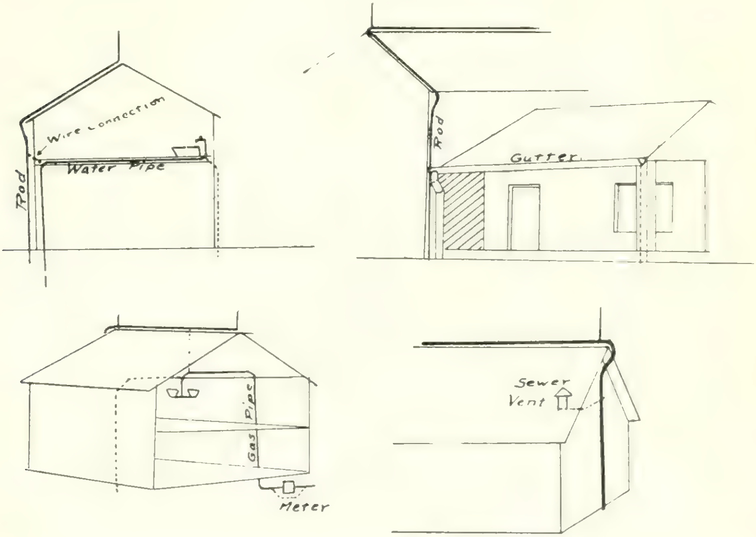


Fig 15. Examples of situations where metal work in or on the building may become dangerous. The connections necessary to make it safe are shown in dotted lines.

Connections to Metal Work in the Building.—Large pieces of metal work about the house are likely to be a source of some danger in two ways. They may be actually struck and form part of the path that the lightning discharge uses in getting to ground, or they may be made dangerous simply by the influence of the other nearby conductors that are carrying off the discharge. This second effect is likely to occur in long conductors, such as water pipes, or rain gutters, especially when one end is near to or runs parallel with one of the rods and the other end projects away from the rod. Sparks may occur at the end of the conductor that is farthest from the rod.

It may be well to discuss briefly some of the commonest kinds of metal work about a house.

Metal on the Roof.—As has already been stated, all tin roofing, metal flashing or lining on ridges or in valleys, all ventilators, weather-vanes and ornamental iron work should be connected to conductors leading to the ground and the connection should be at the lower edge or end of each piece.

Gutters and Rain Spouts.—These are usually so located that they can be made to form a valuable part of the system of protecting

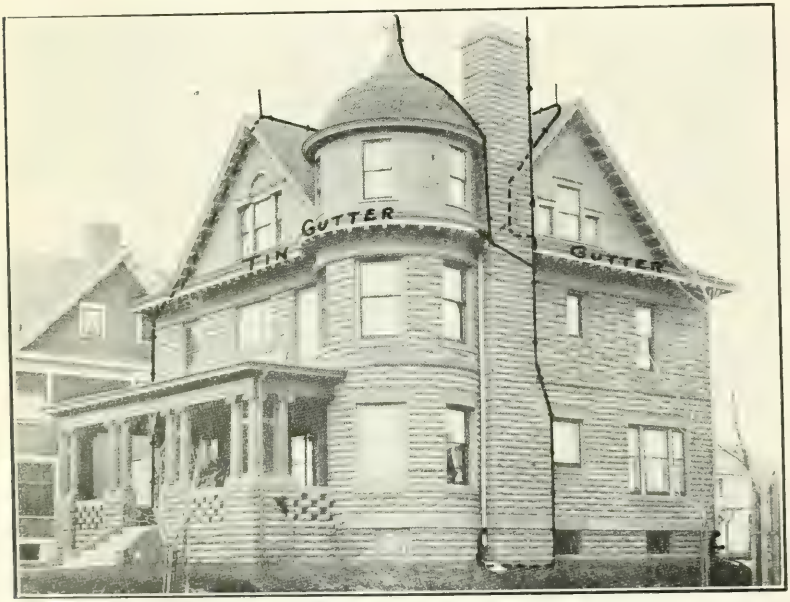
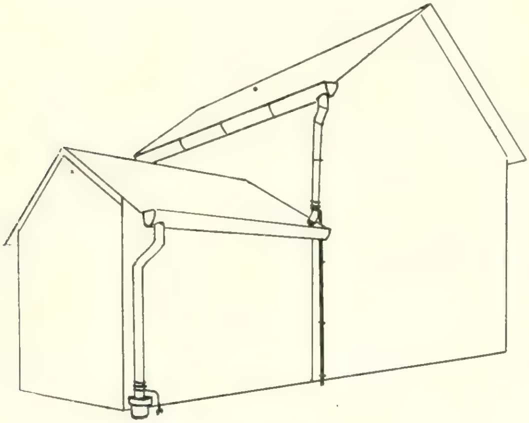


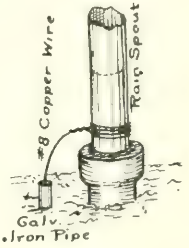
Fig. 16. Rain gutters serve to tie the different rods together, and also to protect the eaves where they are not very much exposed.

conductors, but in using them in this way three points must be kept in mind:

1. They should not be the sole protection except for less exposed points. On flat roofed buildings where the gutters run to the points that are in most danger, they should be connected to the ground by rods at the corners, placing no reliance on the rain spouts.



Case where the path offered by Rainspouts is too indirect.



Connection to Rain Spout

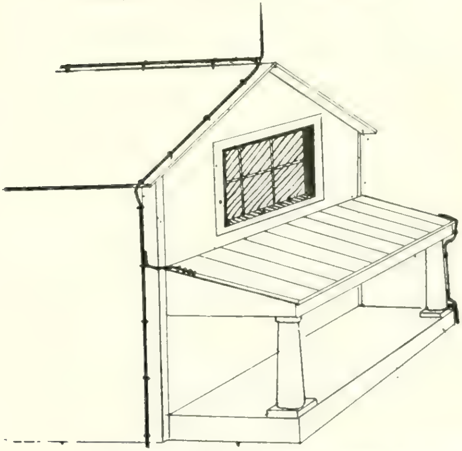


Fig. 17. If a rod passes near one corner of a tin roof, connect the two together and make a ground connection at the far corner.

The rain spouts, however, should be grounded. The gutters and rain spouts should be allowed to help out the rod in carrying off the discharge, but the rods should also be arranged so that they can help the rain spouts to carry it off. The reason for this is that the rain spouts frequently rust out before long and the joints are very poor electrically.

2. The path formed by the gutters and spouts is frequently too long and roundabout. In this case an extra connection should be made giving a more direct way for the lightning to reach the ground. See Fig. 17.

3. A good ground connection must be provided at the bottom of all rain spouts, whether they enter the earth or not. Spouts that are carried into the ground usually only reach a short way down, or else the rain water is carried off in tile pipes which are of non-conducting material.

Interior Metal Work.—Extensive piping inside the house greatly complicates the problem of lightning protection. There are two general methods of taking care of such piping:

1. Connect all ends of gas or water pipes either to the ground or to one of the lightning rods by means of stout wires. If any pipe or metal furnace flue passes within ten feet of a rod make a wire connection across between the two. At least one end of every pipe must be connected with the ground. Make ground connections to the furnace and to the kitchen stove. Figure 15 shows some of the cases where such connections are necessary. Special care must be taken of gas pipes, especially if they are of lead, keeping them well away from the rods if possible.

2. Interior piping may be rendered safe by making the system of conductors on the outside so complete that the lightning would have no tendency to make use of the conductors in the house. In order to do this, lines of conductors should be run along all hips and ridges, along all roof edges and eaves, and a vertical rod with a ground connection should be provided at each corner. At the same time the rods should all be kept at least ten feet away from any of the inside metal work

This second plan will ordinarily be easier to carry out, and is safer for any one who is not an expert.

Stoves.—Stoves, especially kitchen ranges that are in use during the summer, are objects of some danger in thunderstorms, and a connection with the ground should be made by means of a No. 10 or No. 8 copper wire. The wire may be soldered to the piece of sheet zinc or iron on which the stove rests, or attached to the stove by one of the bolts with which the legs are fastened. The wire may run directly to a pipe driven through the cellar floor or may pass through the wall to a lightning rod outside.

Electric Wiring.—Electric wires can not be connected with the ground directly, as in the case of other metal work, but grounded wires may be run **near** the electric wires so that lightning will jump across at this point instead of somewhere else.

Properly equipped telephone sets are provided with "lightning arresters" and wires running to the ground.

Electric light wires are not always provided with any special arrangement to guard against lightning. It is well to observe the following precautions: If the wires are run through the building in iron pipes, the pipes should be connected with the ground. If the main switch that controls the supply of electricity to the house is in an iron box, the box should be connected with the ground. If this switch is not provided with an iron case, a grounded wire should be attached to the meter case.

Electric light wiring and fixtures, and also telephones, should be so placed in the house that it would be impossible to stand on a hot-air register or in a bath tub, or next to a washstand or sink or radiator, and at the same time reach an electric light switch or wire. This is a precaution not only against lightning, but also against danger resulting from accidents to the wires outside.

Sewer Vents.—It is common practice to run an iron ventilating pipe from the sewer up through the roof. If the sewer is as deep as five feet below the surface of the ground, and if it is of cast iron where it goes through the cellar wall, no attention is required. If the sewer is of tile pipe where it goes through the wall, a ground connection should be made for the vent pipe.

OTHER PROTECTIVE MEASURES.

Personal Safety.—The question where is the safest place to be during a thunderstorm must be answered in a general way. Do not stand near the **end** of any line of metal conductor that may become part of the path of a lightning discharge. Do not place yourself where you may become a link in a chain of conductors that may be used by the lightning. A conductor near by will increase your danger in one position and reduce it if you are in a slightly different position. The best rule is probably to keep away from all metal work that is of any size. Especially, do not stand between electric light fixtures or wires on the one side and plumbing, radiators or hot air registers on the other side. Small metal objects are of no consequence. Stoves may be dangerous during a storm. It it just as well not to use the telephone or turn electric light switches. Do not sit or stand close to where a lightning rod runs down the outside of the building. A mental bedstead is an exception to the rule to keep away from large conductors, as the bedstead is shaped so that it very effectually protects the person in it.

The danger from open windows and doorways has probably been exaggerated, but it may be better to keep them closed unless they are covered with wire netting, in which case it makes no difference.

A person caught in a storm naturally seeks shelter from the rain, and frequently the nearest shelter is a tree. Many people have been killed by the tree's being struck, but with a little precaution there need be no more danger under a tree than elsewhere.

Do not select the tallest tree of a group.

Do not run to a single tree standing by itself, if it is possible to reach a place where there are several trees together.

Do not stand close to the trunk; keep as much as four feet away.

Do not stand where the branches are close overhead.

It is better to sit or squat than to stand. Some statistics have been gathered regarding deaths by lightning outdoors, which show that considerably more people are killed in the open than under trees; but these figures do not prove anything, because it is not known what proportion of people caught in storms take shelter under trees.

Lightning and Trees.—There is considerable difference in the liability of different trees to lightning stroke. In Belgium a record was kept for several years showing the number of trees of different kinds that were struck. Poplar suffered most, oaks next and elms third. Pine, fir and chestnut trees are also struck frequently, while the beech, birch and maple are not damaged much. The beech seems to be the safest of all, and for this reason is a good tree to plant in places where people or cattle are likely to take refuge under it in a storm. Observations of lightning strokes were carried on for a period of eight years in a German forest of 45,000 acres. Although nearly 70% of the forest consisted of beeches, there were only 21 cases of damage found. Oaks, which make up 11% of all the trees, were struck 20 times, and firs, which constituted about 6% of the forest, were struck 59 times. It does not follow that a beech tree close to a house will keep off lightning. The beech is safe only because it does not attract the lightning. The location of a tree, however, has more to do with its liability to lightning stroke than its shape or kind.

Resuscitation.—Persons sometimes receive violent electric shocks and appear to be killed, but revive after a time if their breathing is kept up artificially. If someone is struck or shocked and stops

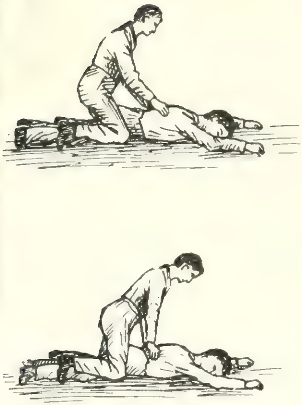


Fig. 18. Producing artificial breathing.

breathing, begin at once to force the breathing, first seeing that there is nothing tight around the neck and no obstruction in the throat. Reach in the mouth and pull the tongue forward and see that it stays so. Loosen all clothing that is tight, but do not uncover the patient unnecessarily. Place the patient flat on the floor, face down, but with the head turned to one side, and with the arms stretched out above the head, kneel with one knee each side of his thighs, place your hands on his lower ribs and press firmly down and inward, gradually throwing your own weight against him, hold the pressure for an instant and then slowly let go. Do this about once in five seconds. This should be continued for at least two hours, if necessary, or until a doctor arrives and finds that the heart has stopped beating. Cases are known of patients recovering after three hours of forced breathing. The work should not be done in a hurried or excited manner. Keep the patient warm. Let someone rub his limbs, stroking them upward, toward the heart, so as to assist the circulation. If the work takes more than a very few minutes, have your assistant apply cloths dipped in hot water and wrung out, to the chest and sides and any other part of the body that may be getting cold, but do not let anything interfere with your efforts to make the patient breathe. Stiffness or resistance to your movements is a good sign. Keep watch for any sign of natural breathing and as soon as it appears, make your movements fall in with it and help it out.

1 hr.
or until

Grounding Wire Fences.—Many cattle are killed every year by standing close to wire fences during storms. Lightning strikes the wire and has no means of getting into the ground, but spreads along the wires and jumps to near by objects.

This danger can be avoided by making a ground connection with the fence every hundred feet. If the fence is long or if there are only a few cattle in the enclosure the ground connections might be put two hundred feet apart, although the protection is not quite so good with this spacing.

Drive a crow-bar four or five feet into the ground and pull it out, run a wire down the hole, making sure that it reaches bottom, give it about two turns around each strand of the fence and a few extra turns around the top wire. If the fence is of wire mesh or network, it is only necessary to make a connection at the bottom. No. 10 B. & S. copper wire is recommended for this work, but if the fence is already old and will have to be replaced in three or four years, No. 8 or No. 10 galvanized iron wire might as well be used. Using the iron wire would save three or four cents on each connection. If the fence is just being put up, fasten the ground wire to the post before it is set in the hole. If the hole is less than four feet deep the wire should be run below the bottom of the post.

Protecting Hay Stacks.—There is much loss from hay stacks set fire to by lightning. A method is suggested here for protecting hay stacks. The apparatus can be put together at odd moments and at small expense. It can be set up over the stack in a few minutes, taken down when the stack is removed, and kept for use the next year.

Get four light sticks about 1 inch by 2 inches by 6 feet, and one piece, say, 2 inches by 2 inches by 10 feet. Sharpen the ends so that they can be thrust into the stack, and drive spikes through to keep them from working further in than is intended. Get a five foot iron rod and fasten it to the end of the large stick so that it projects three feet. File the rod to a point. Fasten to it four No. 8 galvanized iron wires long enough to reach from the top of the stack to the ground. Get four ⅝-inch pointed iron bars, four feet long, and fasten these to the ends of the wires. The four lighter sticks are to

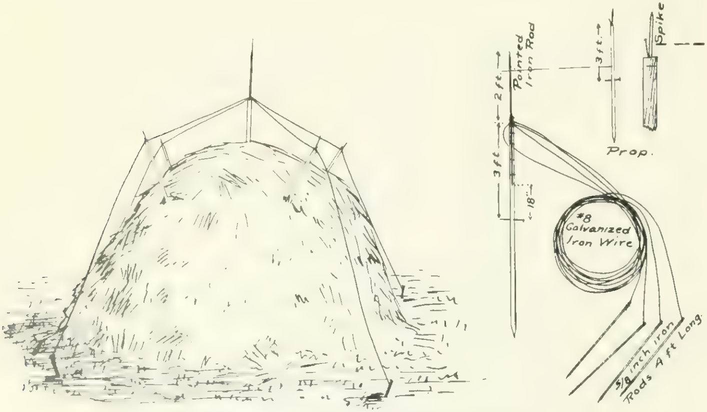


Fig. 19 Apparatus for protecting a haystack.

serve as props to keep the wires well away from the hay. Drive a large spike into the end of each, cut off the head and file it to a point. Drive in a nail next to the large spike so that the wire will wedge between them and make a good contact with the spike. The stick with the wires attached is put in the top of the stack, and the wires stretched out in four directions. Drive the iron rods into the ground. Dig a pit next to each rod and pour in a bucket of salt water. If the stack remains in the field for several weeks of dry weather pour in some more water.

Another method of protecting stacks is to set a light pole in the ground tall enough to reach eight or ten feet above the stack. Attach a rod of No. 4 copper wire to the pole pointed at the top and making a good ground connection at the bottom. Stack the hay around the pole. This will not give as good protection as the first method.

Hay Barns and Silos.—The question has been raised whether ventilators in hay barns increase the risk. Open windows or ventilators may cause greater risk if the barn is not rodded. If a rod with a point is placed directly over the ventilator, the barn is probably safer than it would be without any opening for change of air.

Wooden silos are easily protected with a rod and need the protection. If the silo is made of reinforced concrete it is doubtful whether a rod would be of much use. A lightning stroke would probably scale off and crack the concrete here and there, but not do very serious damage.

THE UNIVERSITY OF MISSOURI BULLETIN

Bulletin No. 8

ENGINEERING EXPERIMENT STATION SERIES

VOLUME 3. NUMBER 2

FIRING TESTS ON MISSOURI COAL

BY

H. N. SHARP

UNIVERSITY OF MISSOURI
COLUMBIA. MISSOURI
June, 1912

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1st, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and one research assistant together with a number of teachers who have undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

NOTE BY THE EDITOR.

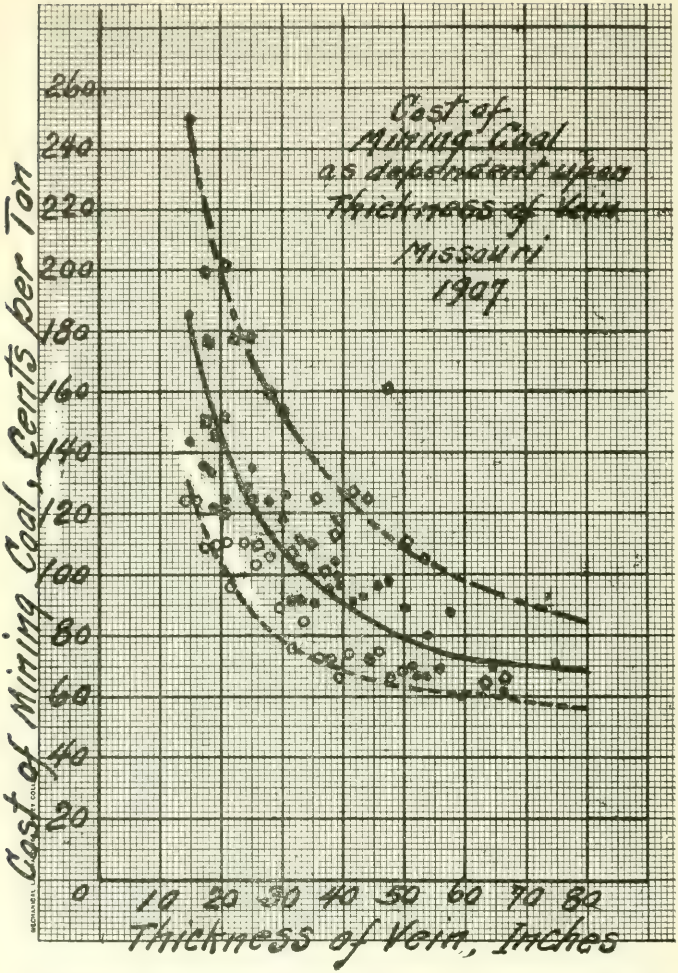
One can hardly overemphasize the importance of an adequate supply of local coal for domestic and industrial use or the value of definite information in regard to its location and quality.

The Engineering Experiment Station of the University of Missouri has published a bulletin, Vol. II, No. 1, "The Heating Value and Proximate Analysis of Missouri Coals", a reprint of a bulletin by Professor C. W. Marx and Dr. Paul Schweitzer, first issued in 1901. There is also available a bulletin "The Storage of Coal" by E. A. Fessenden and J. R. Wharton issued prior to the establishment of the Station. Both of the above are somewhat technical in character, whereas the present bulletin is more directly practical, and shows that the Missouri coal used compares favorably with other bituminous coals mined in the middle west, a fact confirmed by some boiler acceptance tests made under the direction of the writer.

Of prime importance in considering the mining, sale, and use of Missouri coal is the effect of the thickness of vein upon the cost of mining. As more than half the total cost of coal purchased outside the state is for freight and haulage to cities in the middle of the state, there is great opportunity for the development of local coal fields with short-haul transportation. Successful competition with outside coal depends on the reliability of supply, which probably necessitates storage, and on the total cost delivered. If the cost of mining and transportation of Missouri coal for local use can be made even slightly less than competing coal of corresponding heating value, and if coal is available as needed, sufficient capital for development should be easily obtainable, with resulting economy to both mine operators and users.

The cost of transporting short distances can easily be made low by providing proper facilities, but on the other hand the cost of mining very thin veins may be prohibitively high, and unfortunately the coal veins thin out considerably near the edges where they outcrop.

To get the approximate effect of the thickness of vein upon the cost of mining I tabulated the data contained in the "Twenty-first Annual Report of the Bureau of Mines and Mine Inspection, State of Missouri, 1907", and for convenience constructed the accompaning chart which shows the maximum, average, and minimum costs per ton of mining coal plotted against the thickness of the vein.



Naturally other influences affect the cost of mining, so the chart should be considered as a general representation, not as an exact measure of the cost in a particular instance. For example, the chart evidences that it will not generally pay to mine very thin veins except possibly for individual use where the cost of transportation is very low.

H. B. SHAW.

INTRODUCTION.

Half of the 114 counties in Missouri, more than one third of the total area of the state, are underlaid with coal. The coal is bituminous (soft) and compares favorably with other Western bituminous coals in heating value and general adaptability for power plant purposes. The coal mining industry, however, is not very well developed and a great deal of the coal used in the state for domestic and industrial purposes is shipped in from the neighboring states of Illinois, Kansas and Oklahoma.

The price of Missouri coals at the mines is somewhat higher than in the neighboring states, Illinois for example.* This is because the methods of mining are generally not as good, the coal seams are not as thick and high freight rates make it unnecessary to maintain low prices in competition with a distant market. An increased use of native Missouri coal in preference to that shipped in from neighboring states would stimulate the mines of the state to greater activity and more modern methods of mining. The price of coal at the mine could then be lowered and both consumer and producer would be benefited.

Many coal consumers use Missouri coal. In many cases the results are entirely satisfactory, in others difficulties have arisen to cause dissatisfaction and in some cases have led to the use of coal from other states. It is quite possible that much of the dissatisfaction has been caused by improper methods of handling the coal.

It is the purpose of this bulletin to interest the coal users of the state in Missouri coal and to point out methods and controlling conditions by which better economy may be obtained and the coal burned satisfactorily in small hand fired power plants. No set of definite rules can be given because of the widely different conditions which obtain at different plants, but the discussion covers the nature of the coal, its handling and combustion, together with other factors affecting the operation of a boiler plant. These are all of importance to every one who is interested in fuel burning and fuel economy.

Most of the smaller power plants of the state are equipped with hand fired, return tubular boilers. The boilers and setting are not generally kept in the best condition. More or less scale is allowed to accumulate in the boiler and the setting leaks are usually large.

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*Illinois bituminous coal is used as a basis of comparison in several places in this bulletin because Illinois is the largest coal producing state in the Middle West and because the quality of Illinois coal is generally well known.

The discussion in this bulletin is based on a number of tests made with a representative Missouri coal, hand fired under a return tubular boiler. The boiler and setting were not in good condition. They probably represent about average practice and the results obtained are such as might be expected from the ordinary small plant.

Particular attention is called to the use of slack and screenings. These are very low priced, compared with run of mine and lump coal. They can be used with economy if carefully fired.

Missouri coal is often condemned because of clinker troubles. These may also be largely overcome by careful firing.

PART I

FIRING TESTS ON MISSOURI COAL

TESTS.

The tests were made on one of the boilers in the power plant of the University of Missouri. The boiler is a return tubular boiler, hand fired. The principal dimensions of the boiler are given on page 9.

The fireman used in the tests was selected from the regular force of firemen at the power plant. The same fireman fired all the tests. He handled the fire about as he did every day under ordinary working conditions except that he fired a certain number of shovelsful of coal at regular intervals and was told when to slice or clean. The fire was raked and leveled occasionally and kept free from holes.

The operating conditions were kept as nearly uniform as possible for all the tests. Only one condition was allowed to vary for any one test and this the one whose effect was being investigated.

The boiler was kept in regular use throughout the entire period over which the tests extended. It was cleaned and overhauled at regular intervals just as though no tests were in progress. All this was done in order that the test results might be representative of ordinary power plant operation. Washing out the boiler, cleaning tubes, etc., varied the operating conditions somewhat, so that the tests are arranged in several groups, separated by cleaning periods. The condition of the boiler for any one group of tests was not changed in any way except that it became dirty as the time for its regular cleaning approached.

The test apparatus was left set up ready for use. When a test was to be run the steam pressure and water level were brought to their normal mark; then the fire was cleaned, fired with Missouri coal and the test started with the first firing after cleaning. The same plan was folowed when the test was finished, the test being stopped at the first firing after cleaning. With the exception of the variation in firing methods which were being investigated, the tests were all run under ordinary operating conditions.

An injector was used to feed the boiler. Its capacity was too large so that it had to be started and stopped throughout the test. The feed water was weighed by a Kennicott automatic water weigher; the weigher was tested and found accurate within one-half of one per cent.

The flue gas temperature was recorded on a Bristol recording electric pyrometer which was compared with a high grade mercury thermometer and found accurate within a few degrees.

A record of the percent of a carbon dioxide in the flue gases was made with a Uehling continuous CO_2 recorder. This was checked occasionally by an Orsat gas analysis apparatus and found accurate.

The coal was weighed on the platform scales regularly used in the boiler room.

The steam pressure was taken from a new Ashcroft guage, carefully calibrated. The steam quality was determined with a throttling calorimeter.

All the coal used, except that for test No. 6, was stored in a room in the power house protected from the effects of the weather. The coal used in test No. 6 was exposed to a heavy snow. The coal varied from lump coal to slack. The lump coal was broken up before firing.

Tests Nos. 1, 2, 3, 4 and 5 were made with Illinois coal of average quality. All the other tests were made with a typical Missouri coal from Higbee, Mo.

Special care was taken in sampling the coal used in the tests for the determination of the proximate analysis and calorific value. A shovelful of coal was taken from each car (small boiler room coal passing cars) of coal used during a test when the car was about half full. These were kept until the test was finished, then broken and quartered down to about two pounds. In spite of all precautions taken in sampling it is believed that the ash, as shown by the proximate analysis, is too high is tests Nos. 14, 18 and 27, so that the efficiencies of these tests are probably higher than they should be. The high ash shown by the analysis may be caused by including an exceptionally slaty piece of coal in the sample. For this reason these three tests are disregarded in most of the conclusions drawn. The coal sample was analysed as soon as possible after the test. The heating value was determined by a calorimeter of the Parr type.

TEST DATA.

(The figures in parenthesis refer to the code for boiler tests of the American Society of Mechanical Engineers.)

Tests made by H. N. Sharp, for the University of Missouri Engineering Experiment Station, at the University Power Plant, Columbia, Missouri.

Kind of boiler, Horizontal return tubular.

Kind of fuel, Tests Nos. 1, 2, 3, 4, 5.
Illinois run of mine coal.
All other tests—Higbee, Mo., run of mine coal.

Kind of furnace, hand fired, plain grate.

Method of starting and stopping the test, alternate.
Number of boiler (plant number) 7.

(3) Grate surface		28 sq. ft.
(3.1) Width of grate		6.5 ft.
(3.2) Length of grate		4.31 ft.
(4) Height of furnace (distance from top of grate to shell)		21.5 inches
(5) Approximate width of air space in grate		9-16 inches
(6) Proportion of air space to whole grate area		34.5%
(7) Water heating surface		1200 sq. ft.
(7.1) Outside diameter of shell		5.5 ft.
(7.2) Length of shell		16 ft.
(7.3) Number of tubes		72
(7.4) Diameter of tubes	Outside	3.75 inches
	Inside	3.51 inches
(7.5) Length of tubes exposed		16 ft.
(9) Ratio $\frac{\text{Water heating surface}}{\text{Grate surface}}$		42.8

Test Number	Date 1912	Weather	Object of Test	Date of B—Blowing Down C—Cleaning S—Scraping	Duration of Test Hours	Steam Pressure, pounds per sq. inch		Barometer inches of mercury	Draft between Damper and Boiler, inches of water
						Gauge	Absolute		
	(1)				(2)	(11)		(11.1)	(12)
1	Feb. 8	Cloudy-Snow	Preliminary	C. Jan. 21	8.40	103.	117.4	29.3	0.6
2	21	Cloudy-Snow	Preliminary	C. Feb. 18	10.07	98.	112.3	29.16	0.62
4	28	Cloudy	Preliminary		9.93	99.5	113.9	29.38	0.64
5	Mar. 1	Clear	Preliminary		9.89	106.	120.6	29.74	0.61
6	Mar. 7	Cloudy-Snow	Firing Interval	C. Mar. 3	9.98	100.	114.3	29.18	0.62
7	9	Clear	Firing Interval		9.82	104.	118.5	29.55	0.64
8	11	Cloudy-Rain	Firing Interval		8.50	99.	133.3	29.04	0.63
9	12	Cloudy-Rain	Fire Thickness		9.53	103.2	117.5	29.09	0.62
10	13	Clear	Firing Method		9.58	102.6	116.9	29.13	0.61
11	Mar. 29	Clear	Preliminary	C. Mar. 24	8.68	102.	116.2	28.94	0.47
12	Apr. 2	Clear	Firing Interval	S. Mar. 26	10.13	98.7	112.9	29.0	0.41
13	3	Clear	Firing Interval		10.47	97.6	112.	29.24	0.41
14	4	Clear	Firing Interval		10.20	97.	111.4	29.32	0.4
15	5	Clear	Draft		10.28	100.5	114.8	29.1	0.28
16	6	Cloudy	Draft		9.88	97.3	111.7	29.39	0.25
17	8	Clear	Draft		10.17	95.3	109.7	29.4	0.4
18	Apr. 16	Cloudy	Cleaning Boiler	B.&S.Apr. 12	10.54	96.2	110.5	29.2	0.42
19	24	Clear	Firing Method	C. Apr. 14	9.67	96.5	111.	29.43	0.42
20	25	Cloudy-Rain	Firing Method		10.15	98.7	113.	29.15	0.42
21	26	Clear	Fireman B		10.17	99.5	113.8	29.06	0.41
22	May 8	Clear	Firing Method	C. Apr. 28	10.13	97.5	111.7	28.98	0.4
23	9	Clear	Setting Leakage	S. May 2	10.17	98.	112.3	29.02	0.41
24	10	Showers	Setting Leakage		9.90	95.	109.1	28.77	0.47
25	May 14	Clear	Scraped Tubes	C. May 12	9.98	105.1	119.5	29.26	0.4
27	17	Clear	Firing Method	S.&B.May 13	10.03	100.	114.4	29.33	0.41
28	21	Clear	Moisture		9.88	99.8	114.1	29.05	0.41
30	May 24	Cloudy	Forcing	C. May 23	9.35	99.1	113.4	29.21	0.52

Test Number	Temperature of External Air, Degrees F.	Temperature of Fire Room, Degrees F.	Temperature of Steam, Degrees F.	Temperature of Feed Water, Degrees F.	Temperature of Flue Gases, Degrees F.	Fuel, Kind, Size and Condition	Weight of Coal as Fired, pounds	Weight of Dry Coal, pounds	Weight of Ash and Refuse, pounds	Combustible consumed, pounds	Percent of Ash and Refuse in Dry Coal	Fixed Carbon, Percent	Volatile Matter, Percent	Moisture, Percent.	Ash, Percent.
	(15)	(16)	(17)	(18)	(21)	(23)	(25)	(27)	(28)	(30)	(31)	(32)	(33)	(34)	(35)
1	19	47.2	339.6	60.5	777	Illinois,R. of M.,damp,dirty	7147	6250	1026	5325	16.42	41.5	35.25	12.5	10.53
2	27	60.3	336.3	60.8	748	Do.	7698	6760	927	5845	13.7	42.6	37.7	12.2	7.5
4	28	57.	337.3	60.3	614	Do.	6080	5355	826	4527	15.41	42.55	36.2	12.0	9.25
5	22	53.1	332.0	59.8	653	Do.	6115	5280	994	4280	18.81	40.3	36.65	13.5	9.55
6	34	62.4	337.6	60.3	751	Mo., R. of M., ½ slack, wet	8077	7453	1307	6147	17.52	45.6	35.4	7.73	11.27
7	20	51.3	340.3	59.9	786	Mo. R. of M, little slack, dry	8451	7679	1341	6333	17.48	47.75	35.92	9.2	8.12
8	30	61.7	336.9	59.9	735	Mo., R. of M., ½ slack, wet	6991	6331	......	......	......	46.15	35.9	9.44	8.51
9	30	64.7	339.7	60.0	815	Do.	9487	8478	1929	6551	22.73	42.78	32.6	10.64	13.98
10	26	59.	339.3	59.9	719	Do.	8513	7481	1405	6076	18.78	41.2	32.58	12.12	14.1
11	48	75.	338.8	61.3	660	Mo., R. of M., lump, dry ...	5412	4998	......	......	......	43.35	34.27	7.65	14.73
12	48	72.5	336.7	61.3	713	Do.	7660	7019	1089	5931	15.5	45.6	37.05	8.98	8.37
13	51	75.	336.0	61.6	731	Do.	7812	7184	1231	5954	17.12	44.05	33.0	8.04	14.91
14	64	84.7	335.6	61.3	672	Mo., R. of M., ¼ slack, dry	7368	6816	1126	5690	16.52	38.1	27.43	7.47	27.0
15	68	89.8	337.9	61.6	672	Do.	6872	6267	1111	5156	17.72	45.72	32.82	8.8	12.66
16	59	88.8	335.9	61.8	673	Do.	6097	5569	1035	4534	18.58	45.15	32.89	8.66	13.3
17	51	77.	334.6	61.7	662	Mo., R. of M., ½ slack, dry	6732	6078	958	5111	15.74	45.3	32.5	9.72	12.48
18	46	70.8	335.0	61.6	665	Do.	7403	6829	1178	5652	17.24	42.7	32.5	7.75	17.05
19	60	85.7	335.4	61.8	681	Do.	5647	5238	801	4537	15.39	45.8	37.05	7.25	9.9
20	60	82.6	336.7	62.0	713	Do.	6235	5684	885	4790	15.55	44.63	35.4	8.84	11.13
21	63	87.1	337.2	61.9	729	Do.	6134	5589	974	4616	17.41	44.83	35.34	8.89	10.94
22	68	92.6	335.9	62.3	749	Do.	6797	6218	1091	5128	17.53	43.1	34.17	8.52	14.21
23	68	94.5	336.2	62.6	690	Mo., R. of M., ¼ slack, dry	6689	6237	1132	5105	18.15	44.0	37.05	6.76	12.19
24	72	94.4	334.2	62.4	645	Mo., R. of M., ½ slack, dry	5983	5401	1220	4208	22.58	43.85	35.0	9.72	11.43
25	55	80.1	340.9	61.5	682	Do.	6740	6268	1017	5242	16.21	44.9	35.57	7.01	12.52
27	55	82.	337.6	61.7	780	Do.	7232	6491	1147	5344	17.67	38.81	31.88	10.24	19.67
28	76	96.7	337.4	62.8	745	Do., with 5.62% water add.	6547	5632	963	4471	17.10	39.9	33.2	13.98	12.92
30	74	92.7	337.0	62.8	764	Mo., R. of M., ½ slack, dry	7691	7123	1214	5909	17.05	47.72	35.2	7.39	13.68

Test Number	Dry Coal Consumed per Hour, pounds.	Combustible Consumed, per hour, pounds.	Dry Coal per sq. ft. of Grate per Hour, pounds.	Combustible per sq. ft. of Heating Surface, per Hour, pounds.	B. t. u. per pound of Dry Coal, by Calorimeter.	B. t. u. per Pound of Combustible.	Quality		Total Water fed to Boiler, pounds.	Equivalent Water, from and at 212 degrees F., pounds.	Water Actually Evaporated, Corrected for Steam Quality, lbs.	Factor of Evaporation	Equivalent Water into Dry Steam, pounds.
							Moisture in Steam, Percent.	Factor of Correction (dry steam unity)					
	(46)	(47)	(48)	(49)	(50)	(51)	(54)	(56)	(57)	(58)	(59)	(60)	(61)
1	745.	622.6	27.6	0.556	12221	13896	0.535	99.594	34751	41559	34610	1.1959	41340
2	672.5	581.	24.9	0.518	12822	14134	0.75	99.43	38514	46038	45775	1.1953	45775
4	573.	485.	21.2	0.443	12790	14298	0.137	99.9	29062	34749	29033	1.1957	34715
5	534.5	433.	19.78	0.387	12645	14216	0.365	99.719	27910	33411	27831	1.1971	33317
6	746.	615.5	26.65	0.513	12703	14474	0.239	99.819	36901	44119	36834	1.1956	44039
7	781.5	644.5	27.9	0.537	13440	14770	0.069	99.948	42339	50467	42317	1.1967	50441
8	745.	....	26.6	....	13210	14590	0.137	99.896	34139	40786	34092	1.1947	40730
9	889.	687.	31.75	0.572	12088	14320	Dry	Dry	43674	52252	43674	1.1964	52252
10	782.	635.	27.92	0.529	12180	14550	Dry	Dry	41623	49798	41623	1.1964	49798
11	575.	....	20.55	....	12022	14320	0.205	99.85	28741	34317	28695	1.1949	34263
12	692.	585.	24.7	0.487	13120	14450	0.056	99.969	38507	45995	38495	1.1945	45976
13	690.	572.	24.65	0.476	11910	14220	0.079	99.94	39520	47187	39496	1.1940	47159
14	667.5	558.	23.85	0.465	9690	13790	0.181	99.861	36350	43411	36299	1.1943	43350
15	610.	501.5	21.8	0.418	12410	14420	0.125	99.905	32870	39265	32839	1.1946	39227
16	564.	459.	20.15	0.383	12077	14137	0.442	99.664	30338	36212	30236	1.1939	36090
17	594.	502.5	21.35	0.418	12697	14119	0.453	99.655	35034	41818	34913	1.1936	41674
18	647.7	535.5	23.13	0.437	11786	14292	0.011	99.992	40333	48147	40330	1.1937	48143
19	542.	459.	19.33	0.383	13333	14926	Assumed	99.8	30586	36507	30525	1.1936	36434
20	560.	472.	20.0	0.294	12846	14634	Assumed	99.8	33389	39856	33322	1.1937	39776
21	549.5	453.5	21.22	0.378	12809	14556	Assumed	99.8	32234	38487	32170	1.1940	38410
22	613.5	506.	21.9	0.422	11807	13978	0.419	99.681	34299	40926	34189	1.1932	40795
23	613.	502.	21.9	0.418	12792	14496	0.25	99.807	32163	38367	32102	1.1929	38293
24	546.	425.	19.5	0.354	12972	14859	0.147	99.888	26124	31155	26044	1.1926	31120
25	628.	525.	22.4	0.437	12637	14607	0.114	99.913	37721	45084	37688	1.1952	45045
27	646.	532.	23.05	0.443	11121	14118	0.942	99.284	36670	43788	36407	1.1941	43174
28	573.	455.	20.50	0.379	12637	14873	0.432	99.671	31893	38048	31788	1.1930	37923
30	762.	631.5	27.2	0.526	12406	14355	0.023	99.982	37682	44951	37675	1.1929	44942

Test Number.	Water Evaporated per Hour, corrected for Quality, pounds.	Equivalent Evaporation per Hour, from and at 212 degrees F, pounds.	Equivalent Evaporation per Hour, per sq. ft. of Heating Surface, pounds.	Boiler Horse Power Developed (34.5 pounds from and at 212 degrees per hour).	Per cent of Rating Developed.	Water Apparently Evaporated per pound of Coal as Fired, pounds.	Equivalent Evaporation per Pound of Coal as Fired, pounds.	Equivalent Evaporation per Pound of Dry Coal, pounds.	Equivalent Evaporation per Pound of Combustible, pounds.	Efficiency of Boiler, per cent.	Efficiency of Boiler and Grate, per cent.	Cost of Evaporating 1000 Pounds of Water, Observed Conditions*	Cost of Evaporating 1000 Pounds of Water from and at 212 degrees F.*
	(62)	(63)	(64)	(65)	(67)	(68)	(69)	(70)	(71)	(72)	(73)	(75)	(76)
1	4125	4842	4.03	140.3	93.6	4.87	5.74	6.62	7.92	55.3	52.55	$.1027	$.0863
2	3690	4550	3.79	131.9	87.8	5.00	5.95	6.78	7.83	53.75	51.3	.10	.0841
4	2925	3484	2.91	101.3	67.6	4.88	5.71	6.48	7.66	52.0	49.2	.1023	.0877
5	3377	3367	2.81	97.5	65.0	4.56	5.45	6.31	7.78	53.1	48.3	.1096	.0912
6	3689	4411	3.67	127.8	85.2	4.57	5.45	5.91	7.17	48.05	45.15	.1094	.0918
7	4307	5134	4.27	148.9	99.2	5.02	5.97	6.57	7.965	52.3	47.4	.0997	.0838
8	4011	4792	3.99	139.0	92.7	4.88	5.83	6.43	....	....	47.25	.1024	.0859
9	5482	5482	4.57	158.9	105.9	4.60	5.51	6.165	7.98	54.0	49.5	.1087	.0908
10	4355	5205	4.34	150.9	100.4	4.89	5.79	6.66	8.19	54.6	53.1	.1021	.0863
11	3242	3947	3.29	114.4	76.3	5.32	6.33	6.86	....	....	55.3	.094	.0789
12	3798	4535	3.78	131.3	87.7	5.03	6.00	6.55	7.75	52.0	48.4	.0995	.0833
13	3780	4520	3.76	131.0	87.3	5.06	6.03	6.56	7.92	54.0	53.45	.0988	.0829
14	3557	4250	3.54	123.1	82.0	4.93	5.88	6.365	7.62	53.6	63.75	.1013	.0851
15	3200	3820	3.182	110.8	73.8	4.78	5.71	6.37	7.62	51.3	49.	.1045	.0876
16	3056	3652	3.04	106.8	71.2	4.98	5.92	6.48	7.96	54.3	52.1	.1003	.0845
17	3440	4110	3.42	119.0	79.3	5 21	6.19	6.85	8.16	53.75	52.3	.0962	.0808
18	3825	4560	3.797	132.1	88.1	5.45	6.50	7.05	8.52	57.8	58.1	.0918	.0769
19	3160	3770	3.195	112.7	75.1	5.42	6.46	6.96	8.22	53.4	50.65	.0923	.0774
20	3280	3920	3.26	113.6	75.8	5.35	6.34	7.00	8.30	55 0	52.8	.0934	.0788
21	3165	3780	3.15	109.4	73.0	5.27	6.26	6.875	8.325	55.5	52.1	.0944	.0799
22	3370	4030	3.365	117.0	78.0	5.05	6.01	6.56	7.95	55.2	53.83	.099	.0833
23	3160	3770	3.14	111.0	74.0	4.81	5.73	6.145	7.50	50.2	46.6	.104	.0873
24	2640	3145	2.62	90.2	60.1	4.365	5.20	5.76	7.40	48.3	43.1	.1147	.0962
25	3780	4510	3.76	130.7	87.2	5.60	6.68	7.185	8.60	57.1	55.1	.0893	.0748
27	3625	4330	3.61	125.5	83.7	5.025	6.01	6.70	8.13	56.8	58.3	.0995	.0833
28	3215	3835	3.195	111.1	74.1	4.87	5.79	6.74	8.48	55.3	53.2	.1026	.0864
30	4030	4805	4.05	139.2	92.9	4.90	5.85	6.31	7.61	50.7	48.3	.102	.0855

*If coal costs $1.00 per ton.

Test Number.	Method of Firing	Thickness of Fire, Inches.	Firing Intervals, Minutes.	No. of Slicings.	No. of Cleanings, taking out Clinker.	Per cent CO_2 in Flue Gases.	REMARKS.
	(80)	(81)	(82)	(83)		(84)	
1	Spreading	8.	7.03	1	1	9.5	Firing Interval Irregular.
2	Do	8.	8.39	1	1	9.3	Do
4	Do	7.2	10.45	2	0	7.7	Do
5	Do	6.07	8.86	4	0	6.4	Do
6	Do	5.72	7.59	8	0	8.4	Efficiency appears low because coal sample dried before analyzed.
7	Do	5.12	4.91	7	0	8.1	
8	Do	5.42	9.81	6	....	8.2	Ash not weighed in this test.
9	Do	9.87	6.02	2	2	10.8	Thick fire, large capacity.
10	Alternate	5.91	5.0	4	1	9.0	Large capacity.
11	Spreading	5.6	9.48	1	1	7.22	Ash not weighed in this test. CO_2 appears too low, exh't'd chemical
12	Do	5.0	5.2	6	0	8.8	
13	Do	5.44	7.45	4	0	9.8	
14	Do	5.21	9.72	3	0	10.0	Ash abnormally high, making efficiency appear too high.
15	Do	5.35	7.52	3	0	11.5	
16	Do	5.61	7.52	2	1	12.1	
17	Do	5.93	7.72	2	0	10.2	
18	Do	5.98	7.63	3	0	10.0	Ash abnormally high, making efficiency appear too high.
19	Alternate	6.1	7.44	2	0	9.3	Steam quality assumed, accident to calorimeter.
20	Do	6.0	7.52	2	0	10.0	Do
21	Do	4.7	7.44	2	0	9.5	Do
22	Do	5.47	5.47	2	1	10.1	
23	Do	5.17	5.55	4	2	8.1	16″ x 16″ door in rear of setting open about 4″.
24	Do	5.21	5.17	4	2	6.9	16″ x 16″ door in rear of setting wide open.
25	Do	5.12	5.3	5	0	10.2	
27	Spreading	5.03	5.52	4	0	10.5	Ash abnormally high, making efficiency appear too high.
28	Alternate	4.73	7.71	2	0	9.9	5.62% water added to coal to find the effect of wetting.
30	Spreading	5.24	5.61	3	2	11.8	Thickness of fire varied from 4½ to 8 inches.

THE TEST RESULTS.

General.

It is noticeable that the Missouri coal gave as good, or slightly better, average efficiency than the Illinois coal. The boiler was in a little better condition for the Missouri coal tests than for the Illinois coal. This may account for the slightly higher efficiency with the Missouri coal. These two kinds of coal are so much alike that there should be but little difference in the economic results obtained from them. The fireman had no difficulty in firing the Missouri coal and stated that he would as soon fire one as the other.

These observations are confirmed by the United States Geological Survey tests with Illinois and Missouri coals fired under a Heine boiler. These tests comprised a large number of trials with Illinois coals and a smaller number with Missouri coals. The average boiler and grate efficiency with the Illinois coals was about 64%, while that for Missouri coals was 62%.

Firing Methods.

The system of firing employed, whether "spreading" or "alternate", appears to have but little effect upon the efficiency. The efficiency of boiler and grate for all of our tests on Missouri coal grouped by the method of firing is given in Table I.

TABLE I.

EFFECT OF METHOD OF FIRING.

SPREADING METHOD			ALTERNATE METHOD		
Test No.	Efficiency of Boiler.	Efficiency of Boiler and Grate.	Test No.	Efficiency of Boiler.	Efficiency of Boiler and Grate.
	%	%		%	%
6	48.05	45.15?	10	54.6	53.1
7	52.3	47.4	19	53.4	50.65
8	.....	47.25	20	55.	52.8
9	54.	49.5	21	55.5	52.1
11	.....	55.3	22	55.2	53.83
12	52.	48.4	23	50.2	46.6
13	54.	53.45	24	48.3	43.1
14	53.6	63.75?	25	57.1	55.1
15	51.3	49.	28	55.3	53.2
16	54.3	52.1			
17	53.75	52.3			
18	57.8	58.1?			
27	56.8	58.3?			
30	50.7	48.3			
Mean	53.21	52.02	Mean	53.84	51.16
Mean, with tests marked (?) omitted,		50.3			

If the results of all the tests are taken the spreading method appears to be slightly better, but if certain tests (marked ?) are thrown out because of probable errors in sampling the coal for the determination of the calorific value, the alternate method gives results a very little better than the spreading method. The difference is so small that it might easily be explained by many other causes, such as the thickness of the fire, the draft or the firing interval.

Further light may be shed on the question of the method of firing by examining certain tests with all the operating conditions nearly the same. The tests collected in Table II were run with a fire thickness between 4.7 inches and 6.1 inches, the average being 5.49 inches. The draft ranged between .4 inches and .47 inches of water, averaging .42 inches. The load carried was from 110 to 131 boiler horsepower and the firing interval varied as indicated.

TABLE II.

EFFECT OF METHOD OF FIRING.

SPREADING					ALTERNATE				
Test No.	Draft, inches.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.	Test No.	Draft, inches.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.
				%					%
12	.41	5.	5.2	48.4	22	.4	5.47	5.47	53.83
13	.41	5.44	7.45	53.45	25	.4	5.12	5.3	55.1
17	.4	5.93	7.72	52.3	19	.42	6.1	7.44	50.65
11	.47	5.6	9.48	55.3	20	.42	6.	7.52	52.8
					21	.41	4.7	7.44	52.1
			Mean	52.36					
									52.89

This table of test results, selected with the idea of eliminating all the variables except the two methods of firing, shows that there is but little choice between them, the alternate method giving slightly better results.

This conclusion is confirmed by the following results published by the United States Bureau of Mines, Bul. No. 23. This bulletin gives the data of a very large number of boiler tests upon a 210 H. P. Heine boiler, handfired, with coal from all parts of the United States. Table III is compiled for the several Missouri coals used.

TABLE III.

RESULTS WITH MISSOURI COALS.

U. S. Geological Survey Fuel Testing Plant. 210 H. P. hand-fired Heine boiler.

Test No.	Designation of Coal.	Kind of Coal.	Draft, inches.	Thickness of Fire, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.
ALTERNATE METHOD.						
						%
326	Mo. 6	Lump	.73	6	3.6	63.40
327	Mo. 6	Lump	.75	6	3.9	60.64
15	Mo. 1	Small coal and slack	.37	8	4.5	62.32
70	Mo. 4	Small coal and slack	.52	8	5.6	60.06
319	Mo. 5	Run of mine	.61	8	4.2	61.57
329	Mo 7A	No. 1 nut	.60	8	3.5	61.26
330	Mo. 7A	No. 1 nut	.71	8	3.3	60.49
12	Mo. 1	Run of mine	.40	9	4.7	63.18
320	Mo. 5	Run of mine	.73	10	3.6	62.90
332	Mo. 10	No. 2 nut	.71	10	4.1	55.92
				Average		61.17
SPREADING METHOD.						
78	Mo. 3	Small coal and slack	.70	6	6.9	58.94
37	Mo. 2	Small coal and slack	.62	7	6.7	59.45
44	Mo. 2	Small coal and slack	.32	7	8.3	60.68
77	Mo. 3	Small coal and slack	.65	7	7.1	56.93
				Average		59.00

If tests Nos. 332 and 77 are omitted as being considerably lower than the others the efficiency becomes 61.76% for the tests with alternating firing and 59.69% for spreading firing.

Similar results were obtained in a series of tests to determine the best method of firing with Illinois coal conducted by the United States Geological Survey. Table IV exhibits these. (See Bul. No. 373 U. S. Geological Survey or Bul. No. 40 U. S. Bureau of Mines, page 146.

TABLE IV.

EFFECT OF METHOD OF FIRING.

U. S. G. S. Test No.	Method of Firing.	Firing Interval, minutes.	Black Smoke. %	Efficiency. %
500 504	Alternate	3.5	15.8	59.87
505	Alternate	3.4	14.9	60.20
503	Ribbon*	2.3	5.0	62.22
501	Spread	9.3	32.0	57.56
502	Coking	7.4	15.0	60.49

*Ribbon firing is a special type of alternate firing. In the test quoted the doors were fired alternately. This test shows a higher efficiency than any of the other methods and about 5% higher than the spreading method.

Firing Interval.

Authorities on steam boiler practice are united in the opinion that the operation of a boiler is improved by firing the coal in small quantities at short intervals of time. There is a limit to the short interval, however, which is reached when the inrush of cold air through the fire doors causes a loss which balances the gain due to better combustion and constant fire conditions.

There is no question but that firing "little and often" will do much towards preventing smoke. This is borne out by the results of Table IV. In this series of tests the amount of black smoke produced was approximately proportional to the firing interval. It was not possible to make any observations on this phase of the question in the tests run at the Engineering Experiment Station because all the boilers in the power plant, including the one tested, discharge their smoke and gases into a common stack.

The data in Table IV indicates that the efficiency increases as the firing interval decreases. This is to be expected in the light of what has just been said about smoke prevention because smokeless firing is efficient firing unless smokelessness has been secured by admitting a very large amount of excess air.

The results of our tests collected in Table V show in a general way that short firing intervals are accompanied by higher efficiency when the alternate method of firing is used but not for the spreading method.

TABLE V.

EFFECT OF FIRING INTERVAL.

SPREADING.				ALTERNATE.			
Test No.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.	Test No.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.
			%				%
7	5.12	4.91	47.4	10	5.91	5.	53.1
12	5.	5.2	48.4	25	5.12	5.3	55.1
30	5.24	5.61	48.3	22	5.47	5.47	53.83
9	9.87	6.02	49.5	21	4.7	7.44	52.1
13	5.44	7.45	53.45	19	6.1	7.44	50.65
15	5.35	7.52	49.	20	6.	7.52	52.8
16	5.61	7.52	52.1	28	4.73	7.71	53.2
17	5.93	7.72	52.3				
11	5.6	9.48	55.3				
8	5.42	9.81	47.25				

Thickness of Fire and Clinker Troubles.

It was our intention to make tests to show the effect of different thickness of fire. The idea was abandoned after one test, No. 9. This test was made with a thick fire, averaging 9.87 inches, and so much trouble was experienced with clinker that the fire had to be cleaned twice in the 9½ hours run. This test clearly demonstrated that the clinkering properties of this coal prevented its successful use with thick fires.

Thick fires are generally economical because the higher resistance to the passage of air through the grate and fire bed reduces the amount of excess air entering the furnace and thus increases the temperature of the fire and gases of combustion. In general these are conditions desirable for high efficiencies, but they are not desirable when the coal has a tendency to form clinker. The high temperature of the fire bed causes the ash to melt and fuse together. The result is a clinker.

A similar condition of affairs is shown in Tests Nos. 23 and 24. In these tests, although the fire was not thick, the draft over the fire was low, only about 1-10 inch of water. This resulted in a low air supply and a hot fire. A heavy clinker formed and the fire had to be cleaned twice during the ten hour tests.

In Test No. 30 an attempt was made to get the maximum capacity out of the boiler. The fire was forced too much and very bad clinker formed. The fire had to be cleaned twice and the capacity reached was not as high as in Test No. 10. In Test No. 30, however, the coal was very poor, being mostly slack and fine dust. More coal was fired than would burn and the fire varied from 4½ to 8 inches in thickness*. The average thickness was 5.6 inches. The principal difficulty in this test was that the fire was too thick for the fine coal which was being fired.

Tests Nos. 15 and 16 were also run with low draft, but in these cases the coal contained but little slack and the capacity developed was not large. These factors account for the absence of much clinker.

Wetting Coal.

Test No. 28 was made to determine the effect of wetting the coal upon the efficiency. Wetting the coal will often benefit clinker troubles by keeping the fire bed cooler. When fine coal is being fired wetting the coal sometimes serves as a kind of binder which holds the coal together and reduces the loss of good fuel through the grates. The results of Test No. 28 show a slight decrease in efficiency when compared with Tests Nos. 25 and 27, which are in the same group but which were run with a shorter firing interval. Test No. 28 should be compared also with Nos. 19, 20 and 21 in which the firing conditions are about the same, or with Nos. 15, 16 and 17, where the operating conditions are similar but which are fired by the spreading method instead of the alternate. These comparisons indicate that wetting the coal has but little effect upon the efficiency and that the heat lost in evaporating the water on the coal is balanced by decreased loss of fuel through the grate and by the reduction of clinker troubles. It should be noticed that Test No. 28 required no cleaning and was sliced but twice. This is less than any of the other tests run at about the same time.

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*This wide variation in fire thickness is accounted for by the fact that all other conditions were sacrificed to the endeavor to reach a high capacity with the poor coal. Ordinarily the fire was kept at practically constant thickness.

Test No. 6 was also run with a very wet coal which had been exposed to a heavy snow storm. This is not shown in the analysis of the coal because the glass jar holding the sample was accidentally cracked. The crack was not noticed and the sample dried out before the analysis was made. This test shows an equivalent evaporation per pound of coal as fired about 10% lower than other tests run under the same conditions.

The United States Geological Survey found that the boiler efficiency fell off about 1% for every 3% increase in the moisture in the coal.

In general it is important to keep coal dry and protected from the weather. Besides the loss in efficiency which often results from the use of wet coal, it is well known that wet coal, unless stored submerged under water, deteriorates more rapidly than coal which is kept dry and protected from the weather.

Cleaning.

The greatest improvement in the efficiency of the boiler appears when the effect of cleaning the boiler is invstigated. This is well shown in Table VI, by the tendency of the higher efficiencies to collect at the top of the table in the region up to 6 days after cleaning.

TABLE VI.

EFFECT OF CLEANING.

Test No.	Days after Cleaning.	Efficiency of Boiler & Grate.
25	1	55.1 %
11	3	55.3
18	4	58.1
22	6	53.83
7	6	47.4
12	7	48.4
28	8	55.3
13	8	53.45
8	8	47.25
9	9	49.5
10	10	53.1
19	10	50.65
15	10	49.0
20	11	52.8
16	12	52.1
21	11	52.1
17	13	52.3

It is to be noted that the efficiency for the first few days after cleaning is increased by 5% to 6% over the average of all the tests. This indicates the importance of frequent and thorough cleaning of the entire boiler.

In these tests the boiler was fed from a cold water supply through the injector. The cold water contains considerable scale forming material. In the intervals between tests the boiler was fed with hot water from the heating returns passed through feed-water heaters.

Geo. H. Barrus (Engineering Record, June 24, 1911, p. 690) describes two tests to show the effect of cleaning the heating surface of a boiler. The evaporation increased about 5% after cleaning.

Air Leakage in Setting.

Tests Nos. 22, 23 and 24 were made to determine the effect of air leakage in the setting. It is known that the setting itself is about as tight as any ordinary boiler setting in average condition. The leakage was increased by opening the 16″ x 16″ cleaning door in the rear of the setting about 4 inches on Test No. 23 and wide open on Test No. 24. For Test No. 22 this door was closed and the boiler operated under ordinary conditions. The same firing conditions were maintained for the three tests. The results are:

Test No. 22, door closed.........	53.83% efficiency	10.1% CO_2
23, door open 4″.......	46.6	8.1
24, door open wide.....	43.1	6.9

These indicate the importance of making the setting as tight as possible. They also show that the percent of carbon dioxide in the flue gases is indicative of the amount of air leakage.

Firemen.

The fireman is by far the most important factor in securing higher boiler economy. A good fireman is careful and consciencious in the handling of his fire and studies his boiler and his fuel in an endeavor to get the largest possible evaporation per dollar's worth of coal fired. A good skillful fireman can undoubtedly increase the efficiency of the operation of a boiler by 10% to 15% over that secured by an indifferent and careless fireman. A really good fireman is not easily picked up and when one is secured it is well worth while to pay him enough to secure his interest and loyalty to the plant.

A series of tests described in the Engineering Magazine, Vol. 40, p. 83, shows this difference in firmen clearly. The boiler upon which the tests were made was equipped with a Hawley down-draft furnace. One fireman fired large quantities of coal at long intervals and frequently threw coal on the lower grate. He claimed that he could not carry the load without this understoking. The second fireman fired small quantities of coal at frequent intervals. He worked the boiler carefully and did not resort to understoking, although he carried a larger load. The efficiency with the first fireman was 67.5% and with the second 81%. The 13.5% gain was due to careful attention and proper firing.

CO_2 Recorder.

Other things being equal a reasonably high percentage of carbon dioxide (about 14% for Missouri coals) is indicative of maximum efficiency. A good CO_2 recording instrument is of considerable value in showing combustion conditions and furnishes a guide for the fireman in handling his fire. This is illustrated by two tests recorded in Power, Dec. 8, 1908. The tests were of 24 hours duration on a 500 horsepower boiler equipped with a Roney automatic stoker, located in the plant of the Malden (Mass.) Electric Co. In the first test the CO_2 recorder was covered so that the fireman could not see it, in the second it was open for his inspection and guidance. The average results were:

Test No. 1. 7.7% CO_2; 59380 lbs. coal used. Equivalent evaporation, 9.9 lbs.
Test No. 2. 11.2% CO_2; 55955 lbs. coal used. Equivalent evaporation, 10.8 lbs.

A CO_2 recorder is a rather delicate instrument and must be carefully attended. In itself it has absolutely no effect upon the operation of the boiler, but if it is used to show what is happening in the furnace its indications may be made the foundation upon which a considerable increase in efficiency may be built.

Summary.

1. An increased use of Missouri coals would stimulate Missouri coal mines, improve their working conditions, decrease the cost of coal and increase the prosperity of the state.
2. Missouri coals, when properly handled, may be used with as high efficiency as any of the bituminous coals of the neighboring states.
3. Missouri coals are not harder to fire than other middle west bituminous coals.
4. The alternate method of firing gives slightly better results than the spreading method.

5. Short firing intervals are desirable with the alternate method of firing.

6. The thickness of the fire must be varied to suit the size of coal fired. For broken run-of-mine coal, under boilers similar to the one tested, the fire thickness should be about 5 or 6 inches.

7. Missouri coal tends to clinker when the excess air supply is low, when the boiler is forced, and when the fire is too thick.

8. Wetting the coal is sometimes successful in reducing clinker and the loss of unburned fuel through the grates. Otherwise it tends to reduce the efficiency.

9. It is highly important that the boiler be kept clean and free from scale and the tubes free from soot. Frequent cleaning and non-scaling water are well worth their cost.

10. Air leaks in the setting greatly reduce the efficiency. The setting should be carefully inspected periodically and all leaks repaired.

11. A careful fireman is a prime requisite for high efficiency and is worth higher wages than are usually paid.

12. A CO_2 recorder may be made a valuable guide to the fireman in handling his fire.

PART II.

GENERAL PRINCIPLES OF COMBUSTION AND BOILER OPERATION.

COAL.

Coal is a solid, opaque, combustible substance consisting mainly of carbon. It is found in layers or seams up to thirty or more feet in thickness in the upper crust of the earth. Coal mines are rarely deep mines. The average thickness of minable coal seams in Missouri is about 4 feet.

Coal is generally understood to be the remains of prehistoric forests of plants similar to those found in tropical countries today, but much larger and much more rapid in their growth. The refuse of these forests which fell to the ground collected for years and centuries until a thick layer, possibly hundreds of feet thick, was formed. Then, by some disturbance on the unstable surface of the earth, this layer of vegetable matter sank down and became covered with water, followed by the disposition of mud and sand which was brought to the sea by the rivers and covered the layer of vegetable matter deeper and deeper. Finally through the combined effects of time, pressure and heat the bed of vegetable matter became a seam of coal. In burning coal we burn the forests of prehistoric times.

Coals from different seams differ in their chemical and physical characteristics. This has caused the division of coal into several classes which have no well defined line of separation. These are:

Anthracite
Semi-anthracite
Semi-bituminous
Bituminous
Lignite.

Anthracite coal is the oldest coal formation. It is very hard, has a bright lustre and is not so dirty as bituminous coal. The common name, "hard coal", describes it well.

Semi-anthracite and semi-bituminous coal are coals which lie between anthracite and bituminous. They closely resemble one or the other of these two larger classes as their names suggest.

Bituminous or "soft" coal, is easily broken and shows a stratified structure clearly. The surface is usually dull, but a freshly broken piece shows some lustre. Bituminous coals often have thin white or bronze colored seams running through them. This is a deposit of earthy or mineral matter which forms ash when the coal is burned.

Lignite has a brown or black-brown color and is soft and easily broken. It often shows a vegetable structure and deteriorates rapidly when exposed to the action of the weather.

Missouri coals are all bituminous coals of about the same general characteristics as the coal of Illinois and the other Middle West coal producing states.

Coal consists of a combination of the following six substances:

- Carbon
- Hydrogen
- Oxygen
- Nitrogen
- Sulphur
- Ash

Carbon occurs in many different forms. Lamp black and soot are nearly pure carbon. Charcoal and coke are part of the carbon with the ash of wood and coal respectively. Carbon is the principal combustible material in coal.

Hydrogen, oxygen and nitrogen are gases. Hydrogen is the only one of them that is combustible. When it is supplied with the proper amount of oxygen it burns with a very hot, nearly colorless flame. The product of the union of hydrogen and oxygen in combustion is highly superheated steam and may be condensed into water.

Oxygen does not itself burn but must be supplied in order for any combustible substance to burn. For this reason it is called a "supporter of combustion."

Nitrogen will not unite with oxygen or other substances under ordinary conditions. It is said to be an inert gas. It forms about 79% of the total volume of the air, the remaining 21% being oxygen. There are a few other gases besides oxygen and nitrogen in the air, but their volume is so small that it is not considered. Nitrogen in coal is usually present in small amounts combined with other substances. The nitrogen in the air and that in the coal does not undergo any change in passing through the furnace and contributes nothing to the heat of combustion. It dilutes the oxygen and increases the total volume of the products of combustion.

Sulphur burns with a bluish flame. It does not occur free in the coal but is combined with other substances. Sulphur is regarded as undesirable in coal. It adds but little to the heating value and is usually thought to increase the tendency to form clinker.

Ash is the inert noncombustible material of coal.

In the "ultimate" analysis of a sample of coal, the amount of each of the six substances just described is determined and is expressed as a percentage of the total weight of the coal.

Coal is often described by the "proximate" analysis. This is much easier to make than the "ultimate" analysis. In this analysis the following four substances are determined and expressed as a percentage of the total weight of the coal:

Fixed carbon
Volatile matter
Moisture
Ash

Fixed carbon is carbon in a nearly pure form. It is the coke which a certain coal will produce minus the ash which is contained in the coke.

Volatile matter consists mainly of hydrocarbon compounds, that is, chemical combinations of carbon and hydrogen. It includes the gases of coal, like illuminating gas, together with tarry vapors and other similar substances.

Moisture and ash are self explanatory.

The method of making the proximate analysis is given briefly below.* It also illustrates the manner in which the various constituents in the coal behave when the coal is burned.

A sample of the coal is finely ground so as to pass a sieve with from 60 to 100 meshes per inch. One gram of this is accurately weighed in a crucible and then placed in a drying oven which is kept at a constant temperature slightly above the boiling point of water under atmsopheric pressure. After one hour the sample is removed, cooled and weighed again. The object of this operation is to drive off the moisture. The loss in weight before and after drying gives the weight of moisture in the one gram sample.

The same sample in a crucible with a loosely fitting cover is then placed over a Bunsen flame of a certain size and left for seven minutes, cooled and again weighed. While heated over this flame the volatile matter in the form of gases, tarry vapors, etc., are driven off and burn around the edges of the crucible cover. After weighing, the difference in weight before and after this operation is the amount of volatile matter. The time seven minutes with a definite size flame has been adopted as a standard, because by longer or shorter heating slightly greater and lesser amounts of the material in the coal would be distilled off as volatile matter. The term "volatile matter" is somewhat loose and there is no well defined point for separating the carbon in the volatile matter from the fixed carbon, except by such an arbitrarily chosen method as outlined.

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*For more complete details see:
Journal of the American Chemical Society, Vol. XXI, No. 12, Dec, 1899. (Published by Chemical Publishing Co., Easton, Pa.)
Also, Technical Paper No. 8, United States Bureau of Mines. (Address "Director, Bureau of Mines, Washington, D. C."

What remains of the original sample is now the coke of the coal. It consists of the fixed carbon and the ash. The fixed carbon is determined by placing the coke sample uncovered over a very hot flame and leaving it there until only the ash remains. This may take several hours. Weighing again the difference in weight before and after burning out the fixed carbon gives its weight. The weight of the remaining ash is then known by subtracting the weight of the empty crucible from the weight of the crucible and the ash.

Summarizing, it is seen that coal is complex in its structure and consists of several chemical elements which may be collected into the substances determined by the proximate analysis.

(a) Moisture.
(b) Volatile matter, consisting of gases and tarry vapors, easily driven off when the coal is heated. It burns quickly.
(c) Fixed carbon, requiring a long time for its combustion.
(d) Ash, incombustible material.

The percent which each of these bear to the total weight of the coal is given in the proximate analysis. Sulphur is occasionally given also, but it is determined separately by an entirely different method.

The classification of coals is often based upon the amount of fixed carbon which they contain. This is not the best classification but it is the one most used.

	Percent of Fixed carbon in the Combustible*	Percent of Volatile Matter in the Combustible.
Anthracite	100 to 92.3	0 to 7.7
Semi-anthracite	92.3 to 87.5	7.7 to 12.5
Semi-bituminous	87.5 to 75.	12.5 to 25.
Bituminous	75. to 50.	25. to 50.
Lignite	50. to 0.	over 50.

Coal is mined in all sizes from large lumps to fine dust. This mixture of sizes just as it comes from the mine is known as "run-of-mine" coal. The run of mine coal is often passed over screens to separate it into different sizes before it is sold. The large lumps which pass over the screen are called "lump coal" and the fine stuff which passes through the screen is called "slack", "breeze" or "screenings". Sometimes an additional screen is used to separate out what is called "sized egg" or "nut" coal. The name suggests the size.

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*By "combustible" is meant the combustible matter of the coal, i. e., the total coal minus the ash and moisture.

At some mines coal is graded according to the following table:
No. 1—Coal passing through 3 inch screen and over 1¾ in. screen
No. 2—Coal passing through 1¾ inch screen and over 1 in. screen
No. 3—Coal passing through 1 inch screen and over ¾ in. screen
No. 4—Coal passing through ¾ inch screen and over ¼ in. screen
No. 5—Coal passing through ¼ inch screen

COMBUSTION.

Combustion is the rapid union of a substance with oxygen. Heat is given off in the process. The substance which burns, or with which the oxygen unites, is called "the combustible".

Carbon burns, or unites with oxygen, and the combustion may be **complete** or **incomplete.**

Complete combustion results when carbon is supplied with all the oxygen with which it can unite. This can be determined by definite laws of chemistry. When complete combustion of carbon takes place an inert, combustible gas, called carbon dioxide, is formed. This gas is sometimes represented by the chemical symbol CO_2.

If the oxygen supply for the carbon is deficient, incomplete combustion will take place. In this case a combustible gas, carbon monoxide (represented by the symbol CO) is evolved.

Heat is always given off when combustion occurs and the same amount of heat* is always generated when a given amount of the same substance is burned to the same completeness of combustion. Thus when one pound of pure carbon is burned completely to carbon dioxide (CO_2), 14500 B. t. u. are always given off. When one pound of pure carbon is burned to carbon monoxide (CO), 4400 B. t. u. are evolved. Furthermore, when the carbon monoxide resulting from the incomplete combustion of one pound of carbon is burned, the product of the combustion is carbon dioxide, and the heat evolved is 10100 B. t. u. Thus the same amount of heat is evolved, viz. 14500 B. t. u., when a pound of carbon is burned, whether the combustion proceeds directly to completeness or goes through two processes to completeness. If the combustion passes through two stages, however, and some of the carbon monoxide passes away unburned, the heat which it would furnish, at the rate of 10100 B. t. u. per pound of carbon, is lost.

The complete combustion† of one pound of hydrogen forms steam and about 62000 B. t. u. are given off.

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*The unit of heat is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. This is called the "British Thermal Unit (B. t. n.)."

†The combustion of most of the substances occuring in coal except carbon is always complete.

The oxygen necessary for the combustion of coal in a furnace comes from the air. Air, being a mixture of oxygen and nitrogen in the proportion of 21% and 79% by volume respectively, supports combustion. The nitrogen of the air passes through the furnace without change. In boiler practice in order to be sure that sufficient air is provided it is necessary to supply somewhat more than just enough air to carry in exactly the amount of oxygen for the combustion. In the best practice only about 40% excess air is supplied, but in many plants the excess may be 200% and more.

The amount of carbon dioxide (CO_2) formed is always the same for the complete combustion of a given weight of carbon, no matter how much excess air is supplied. The per cent of carbon dioxide, or the volume of carbon dioxide compared with the total volumes of all the gases (CO_2, CO, hydro-carbons, air, nitrogen, etc.) leaving the furnace, becomes smaller as the amount of the other gases increase. This can be illustrated by the following example: Suppose a quart of milk and a quart of water are mixed together, the milk will then be one half, or 50% of the total mixture. Now increase the water to three quarts with one quart of milk. The actual amount of milk is the same but now it is only one fourth, or 25%, of the mixture. In the same way the percent of carbon dioxide, CO_2, in the gases leaving the furnace decreases as the amount of excess air increases.

When a shovel full of soft coal is thrown on a bed of hot incandescent fuel, the moisture and volatile gases are first driven off very rapidly, and in large volumes. The action is so rapid and the volumes of gas so large that there is but little opportunity for proper mixture with air for burning. Furthermore, some heat is necessary to warm up the coal and drive off the volatile matter, so that the process cools off the furnace. The volatile gases are the same as those driven off by the Bunsen burner in the proximate analysis. In order to thoroughly understand what occurs in the furnace it is necessary to study those volatile gases.

Experience with common illuminating coal gas, and also with producer gas, has shown that these gases contain a large amount of tar which must be removed before the gases can be used for light or in a gas engine. We should expect to find the same tar present in the volatile gases driven off in a boiler furnace.

An idea of the behavior of the tar in the furnace may be gained by pouring a little tar on a hot iron plate. A dense brown tarry smoke is given off. We know that this is probably not a gas for gases are usually transparent and invisible. It is hard to imagine that this smoke is made up of little solid particles. It is more probable that the color is given to the smoke by small particles of the tar in a liquid or semi-liquid form, like the spray from an atomizer. It is quite easy to imagine tiny little globules of tar, small and light enough to be carried along with the gases. They are similar to the nicotine carried along with tobacco smoke, which may be caught as a deposit if the smoke is blown through a cloth.

The soot deposited on the tubes and that which passes out of the stack and blackens the surrounding neighborhood is evidence of little solid particles of unburned carbon.

Thus in the products passing out of the furnace we may expect to find volatile gases, liquids in the shape of small, round, tarry globules, and small solid particles of carbon. If all of the possible heat of the fuel is obtained all of these things must be completely burned.

There are three conditions necessary for the complete combustion of any substance:

1. A sufficient supply of oxygen, usually in the form of air.

2. The maintenance of a temperature above the ignition temperature of the substance to be burned.

3. A thorough mixture of the combustible with the oxygen or air so that every particle of the combustible may find the oxygen necessary for its combustion.

The first condition is easily obtained in boiler practice by adjusting the air supply with the dampers.

High temperature will follow when good combustion is secured provided the excess air is not too great.

A satisfactory mixture of air with some of the combustible material is the most difficult to obtain. With the true gases the mixture is comparatively easy because it is the nature of gases to diffuse readily and become intermingled into a homogeneous mixture. With the tar globules the problem is quite different and a good mixture is difficult to obtain.

Consider one of the tar globules as it is carried along in the current of gas. It travels at about the same rate as the gas stream so that there is but little tendency for the gases to rub past it or have any kind of scrubbing action upon it. The result is that after the outer layer of the globule is burnt it becomes surrounded by a blanket of inert gases. These do not have time to diffuse into the surrounding gas stream and are not scrubbed away by it so that they prevent further burning of the tar globule by keeping the necessary oxygen from coming into contact with it. The behavior of solid particles of carbon which are formed by the decomposition of some of the gases is quite similar to that of the tar globules, so that these two constitutents of the products of the furnace tend to pass out of the stack incompletely burned. They appear as soot or smoke.

The principles of combustion and the effect of proper mixture and air supply may be illustrated by the common oil lamp.

If the chimney is removed black smoke is formed. This is caused both by the cooling effect of the large amount of air which has access to the flame and because the unconfined air and gases move at a low velocity and do not scrub away the burnt gases fast enough. If the chimney is replaced the air and gases inside the chimney are confined and move with much higher velocity and the flame is protected from the cooling effect of the outer air. The higher velocity of the gas inside the chimney scrubs off the burnt gases so that the air supply from the bottom of the chimney has easy access to the combusible gases. If the hand is placed over the openings at the base of the chimney so that the air supply is cut off, a smoky flame is again produced because the air supply is insufficient.

Going back to where the shovel full of coal was fired, it is found that the fixed carbon is left after the moisture and volatile matter is driven off. The fixed carbon burns as a bed of yellow or white hot coals upon the grate. Air passes up through the grate and burns the first or lower layers of carbon to carbon dioxide (CO_2). In the presence of very hot carbon and little air the carbon dioxide formed unites with carbon in its passage upward through the fuel bed and forms carbon monoxide (CO). This operation takes up heat, 10100 B. t. u. per pound of carbon. The carbon monoxide mixed with some unchanged carbon dioxide issues from the top of the fuel bed and if the carbon monoxide is supplied with air it will burn to carbon dioxide and return the 10100 B. t. u. previously taken up. The air for this combustion may be furnished over the top of the fuel bed or may come from excess air passing up through the grate.

Geo. H. Barrus (Engineering Record, June 24, 1911, p. 690) shows by two tests that an increase of 10% in the equivalent evaporation per pound of coal was obtained by admitting air over the fuel bed to burn the volatile gases and carbon monoxide.

One pound of average Missouri coal gives off about 12600 B. t. u. when it is fully consumed. In the ordinary plant only about 45% to 70% (averaging about 50% in the majority of the smaller plants) of this heat is present in the steam formed. That is, only about one-half of the coal supplied is actually used in making the steam, the other half supplying the losses. There are several of these losses and the majority of them are unavoidable.

1. There is a loss due to unconsumed fuel falling through the grate, or wasted by being pulled out with the clinker when cleaning

the fire. This is a direct loss of unconsumed fuel, but it is unavoidable, except that in many cases an excessive amount is carelessly pulled out in cleaning. This loss is small, usually in the neighborhood of 4% to 6%.

2. The loss due to the incomplete combustion of the carbon that burns to carbon monoxide amounts to as much as 3% to 4%. It can be eliminated by sufficient air supply and proper mixing.

3. The heat lost in evaporating the moisture in the coal may reach as high as 6% in some cases and is unavoidable, except that the percent of moisture in the coal can be reduced to a minimum by keeping the coal in a dry place.

4. There is a loss due to the moisture formed in burning hydrogen, amounting to about 5%. This is unavoidable.

5. Heat radiates from the setting and this loss amounts to some 2% to 5%. It is unavoidable but it can be reduced to a small extent by insulation of the walls of the setting. This is seldom practiced.

6. There is an avoidable loss in the unconsumed fuel which passes out of the furnace in the form of carbon particles and little tar globules and is directly seen as soot and smoke. This loss is often as large as 10% and nearly all of it can be prevented by proper air supply, proper firing and a thorough mixture of air with the volatile gases. The loss due to carbon particles or soot alone is probably 1% or 2%.

7. Another large and partially avoidable loss is that due to the heat carried away by the chimney gases. This loss amounts to as high as 40% in some boiler plants, but by careful manipulation and adjustment of the air supply it may be reduced to about 15% or 18%.

The last two of these losses are large and are the ones which can often be considerably reduced with a corresponding increase in the boiler efficiency.

The loss in the unconsumed fuel which passes out of the furnace with the volatile matter may be reduced in two ways:

First, from the description of the tar globules and their behavior it appears that if sufficient scrubbing action by the hot gases upon the envelop of inert gas surrounding the tar globules could be produced, the loss would be reduced because more of the tar would be burned. To increase the mixing and scrubbing action wing walls and mixing piers are used in the furnace. They tend to break up the stream of gas and form swirls and eddies. They are difficult to keep in repair because of the high temperature to which they are subjected. The second and better method is to prevent as far as possible, the formation of the tarry globules. This is what is accomplished by the use of automatic stokers and down draft furnaces.

In the stoker the coal moves into the furnace slowly and is gradually heated up. The process is not almost instantaneous as when a shovelful of coal is thrown on a hot bed of coals. As a result the gases are distilled off slowly instead of in great volumes all at once. Ample time is thus given for mixing with the air necessary for combustion. The distilled gases must pass over the hot fuel bed and be scrubbed by the hot air rising through it. The little tar globules are exposed to a high temperature longer and may even become gaseous and easily burned. An automatic stoker is coking firing and firing "little and often" reduced to the lowest possible limit.

Stokers have one further advantage in that the conditions inside the furnace are practically constant and uniform, instead of constantly and rapidly changing as in a hand fired furnace. Thus if the draft and air supply are once properly adjusted, they will continue to be correct until the feed of the stoker is changed.

Stokers reduce the boiler room labor costs in large plants but not in small plants.

The down draft furnace also serves to distill the volatile matter slowly.

An important factor in securing complete combustion of the volatile matter is in the use of tile roofs over the grate. If the gases strike a comparatively cool surface, such as the boiler shell or tubes, they are cooled below their ignition point and condensed into the tarry globules which are so hard to burn.

In the hand fired furnace, except the down draft type, it is difficult to prevent rapid distillation because the firing must necessarily be intermittent. Much can be done by breaking the coal into uniform pieces, about egg size, and by carefully scattering small charges of coal at frequent intervals. With small uniform sized lumps of coal the distillation is general instead of localized as is the case when large lumps are fired. In the latter case little opportunity is given for mixing and heating because the volume of the gas distilled at one place is so large.

Frequent firing well scattered gives an opportunity for mixing and approaches the operation of a stoker with continuous distillation.

The loss carried away as sensible heat in the flue gases can be reduced by reducing the temperature and weight of the flue gases. These gases act as a carrier of the heat from the furnace to the boiler. The boiler cannot remove or absorb any heat which exists as heat in the gases below the temperature of the boiler. Thus the gases must always carry off some heat up the stack. When reduced to a minimum this loss is necessary and unavoidable. It is necessary because the hot chimney gases cause the draft which draws air into the furnace and it is unavoidable because it is impossible for the boiler to absorb the heat when the gases are at or near the temperature of the steam.

This loss will be a minimum when the weight of the flue gases multiplied by their absolute temperature is a minimum.

The direct cause of the extremely large loss found in the average small plant is due to the large amount of excess air supplied, for it is this alone that increases the weight of the gases. All the excess air, together with the nitrogen in the required air, is heated from the temperature of the fire room to that of the chimney gases. The heat to do this comes from the coal. The excess air may come through too thin a fire, holes in the fire or leaks in the setting.

The loss of heat from air leakage is apparent. Every fireman knows that if the fire doors are left open the pressure will begin to drop. He never leaves the doors open after firing if he expects to make steam.

It is quite an easy matter to cut down an excessive air supply. In many cases it will be found that the excess air is passing through holes in the fire. This may appear to be a trifling matter, but a few holes in a fire may together have the same area as the fire door. They then admit as much air as the fire door would if it were left open. If it is important to keep the fire doors closed it is just as important to watch the fire and keep the holes in it closed.

The amount of air which a setting, apparently in the best condition, will leak is surprising. The settings of the test boilers of the U. S. Geological Survey plant were kept in the very best condition. One of their bulletins states that one man was almost constantly employed for nothing else than patching air leaks and keeping the settings in good repair. Test results on these boilers showed an air leakage of about 26%, that is, about one-fourth as much air leaked through the setting as was supplied through the grates. It is quite probable that the leakage in ordinary settings is very large, possibly 50% to 70%.

In good practice about 40% excess air is required in order to have sufficient to insure good mixing. This corresponds to about 13% to 14% CO_2 in the flue gases for average Missouri bituminous coal. In many of the average smaller plants 200% or more excess air is admitted. The corresponding proportion of CO_2 is about 6%. The avoidable loss (waste) in such a case is about 10%.

Clinker.

Clinker is caused by the fusion, or melting and running together, of the ash left when coal is burned. It has been shown lately that the ash of different coals have different fusing temperatures. The ash of one coal may fall through the grate unchanged because the temperature of the fire was too low to fuse it, while the ash of another coal under similar conditions may melt and run together to form a hard clinker. The ash with a high fusing temperature may partially melt and become soft so that a thick and pasty, but porous mass is formed which sticks together but still allows the passage of some air. Under similar conditions the ash of low fusing temperature melts and forms a sticky, semi-fluid mass which spreads out and runs over the entire grate, covering it with a thin vitreous clinker which effectually prevents the passage of air. This type of clinker covers a larger area than the other and does not admit even a small amount of air through it. It also tends to run down between the grate bars so that it is very difficult to remove.

When the fuel bed over the grate is cool very little clinker forms. This can be seen by watching the fire just after it is cleaned. At first there is no ash on the grate and the cold air rushing up through the bars, keeps the fuel bed near the grate cool. When the ash begins to collect and pack together the air passages are partially closed up and the cooling action reduced. As a result the temperature of the fuel bed near the grate increases. This tendency continues to increase as the amount of ash collected on the grate increases. Finally a point is reached where the ash fuses and clinker begins to form. Before this the coal burns freely and quickly upon the grate and it requires close attention to keep holes out of the fuel bed. As soon as the clinkers begin to form the coal does not burn so readily and the fire begins to increase in thickness.

Forcing the fire increases the temperature and therefore increases the tendency to form clinker, and the clinker formed is likely to be quite fluid so that it spreads over a large part of the grate area. If it is not removed it gradually reduces the air supply and causes the capacity to fall off because of the difficulty of burning the coal. A clinker of this kind is so soft that it is hard to handle when cleaning or slicing the fire.

The tendency to clinker can often be reduced by wetting the coal, the use of steam jets under the grate or water in the ash pit. All of these means have their effect by cooling down the fire. They all results in a direct loss of heat but sometimes make forcing possible under conditions and with fuel which would not otherwise allow it.

Fire Thickness.

The question is often asked, "What is the best and most economical thickness of fire?" No definite answer can be given because so many variable factors enter into the circumstances which control the best fire thickness.

One of the most important of these factors is the size of the coal used. If the coal is all fine slack the fire must be kept thin. The fine particles of coal pack together and tend to fill up the voids or interstices in the coal, making it difficult for the air to get through. If the fuel bed is thick it may not be possible for enough air to pass through to burn the coal. Only such coal as receives the necessary air will burn, so that a thick bed of fine coal will evaporate less water into steam than a thinner fire bed which allows the necessary air to pass through it. If the draft is increased more air will, of course, be drawn through the thick fuel bed, but the losses from the leakage of cold air through the setting are also increased.

With nearly uniform sized egg coal a thicker fire should be carried than with fine coal because the air easily passes through the larger crevices formed in the bed of larger fuel. In order to keep the excess air down to a reasonable amount it is necessary to make the fuel bed thicker so as to increase the resistance to the flow of air.

In general, the larger the lumps and the less slack in the coal, the greater the thickness of the fuel bed. On account of the difficulty of burning the large volumes of volatile matter set free, it is essential that large lumps be crushed. Lumps larger than a man's fist should not be fired. Besides the difficulty of imperfect combustion of the volatile matter, it is found that large lumps cause a fire to burn in holes. The air comes in around the edges of a lump and burns the surrounding small fuel faster than the lump. Soon a hole is left around the lump.

Up to a certain thickness, depending upon the size of the coal and the draft, a thick fire will give greater capacity because holes are less likely to form. A thin fire requires great regularity of firing and close attention to keep all holes covered. A thick fire is easier to fire and takes less attention, but the economy is likely to be lower. Thick fires are more subject to clinker troubles than thin ones. The draft as well as the size of the coal, is of importance in fixing the proper thickness of the fire. With a low draft, for any size coal, the fire bed must be thinner than with a high draft, because with low draft the resistance to the passage of air must be low. A high draft requires a thick fire to increase the air resistance and cut down the excess air.

Draft Capacity and Rate of Combustion.

In most plants the practice is to use all of the draft available. If the steam pressure rises too high, some firemen open the furnace doors, others close the flue damper, open the breeching door or close the ashpit doors.

The practice of opening the fire doors is very bad, first, because it makes an increased loss due to the large amount of heat carried off by the air, and second, the cold air rushing in cools the boiler plate quickly and causes sudden contractions and temperature stresses. These weaken the plate and produce leaky seams.

Closing the stack damper or opening the breeching doors is to be preferred to closing the ashpit doors, because these do not cause an increase of air to be drawn in through the setting leaks as is the case with closing the ash pit doors.

For a large capacity, the rate of combustion must be increased, a larger amount of coal must be burned on the same grate, requiring more air and a good draft. When boilers must be forced particular attention should be paid to keeping the setting tight and free from leaks.

The rate of combustion depends directly on the intensity of the draft and the thickness of the fire. A thick fire is usually necessary when a large capacity is to be developed but thick fires do not burn coal with the best efficiency. Accompanying a thick fire there is likely to be a large loss due to incomplete combustion of carbon because the air supply is reduced to a minimum.

We found the maximum rate of combustion for the Missouri coal we tested to be about 25 or 30 pounds of coal per square foot of grate surface per hour, with a draft of about .6 inch of water at the stack damper. Even at this rate the fire was white hot and the clinker very soft. Much slicing and cleaning was necessary with a consequent large loss of combustible drawn out with the clinker. A lower rate of combustion would have given a better efficiency and less clinker trouble.

Too high a draft will cause the fine coal to be carried away from the fuel bed unburned. Even a draft of .15 inch of water over the fuel bed was found to carry fine particles over the bridge wall. In locomotive practice the draft is very high, compared with stationary practice, and large pieces of carbon, many one-fourth inch in diameter, are thrown out of the stack. Tests by the U. S. Geological Survey have shown the loss due to these cinders thrown out the stack to be in some cases as high as 5%, with run of mine coal, the draft being about 2½ inches of water over the fuel bed.

Too low a draft will cause a very hot fuel bed and consequently much trouble with clinker. It will be noticed that much the same effect is produced by reducing the draft or thickening the fuel bed as both decrease the air supply.

Cleaning and Slicing.

Fires are usually cleaned or sliced when there is sufficient clinker to cut off the air supply and reduce the capacity appreciably. If the clinker is rather thick, porous and easily broken, such as is obtained by a slow rate of combustion, a slice bar can be run underneath the clinker and raised just high enough to break the clinker a little, shake some ash down and allow more air to pass through the fuel bed. In this operation care must be taken not to raise the slice bar through the fuel bed because the green coal, ash and hot fuel are then all mixed together. This increases clinker troubles, and produces a fire full of holes.

Sometimes a fire is in such a condition that the large clinker can be removed with the slice bar, but unless all of the clinker is removed and a thorough cleaning takes place, the fire is usually left mixed up and in very bad condition.

An attempt to slice a very hot fire where the clinker is in a pasty mass, usually ends in a bad fire with clinkers sticking to the grate. It may be necessary to let the fire cool somewhat before slicing.

The method of cleaning a fire by pulling the clinker out with a slice bar does not waste as much combustible but takes more time than the regular method. It cannot always be done on account of high temperature and soft clinker. The common method of cleaning described below is probably the best way to treat a fire which is not developing the required capacity, unless the clinker is porous and can be broken up by a careful slicing without disturbing the fuel bed.

In the ordinary method of cleaning enough fuel is fired to give a good bed of coals. After it has gotten well started the fuel on one side is thrown or "winged" over to the other side with a bar. Care should be taken to get all of the combustible away leaving only ash and clinker on the grate. This clinker bed is broken up by slipping the bar underneath and raising it up. The mass of clinker and ash is then pulled out of the fire door with a hoe into a barrow or on to the floor. The burning fuel is then scattered over the clean grate by placing the bar in the other door and throwing the fuel back, leaving only ash and clinker on the second side. The first side should now be fired in order to have a good live fire to scatter over the second side when the grate is clean. This will require a good heavy firing.

Before breaking up the second side it is well to let the fire burn a while to get a good start. If the clinker is very hot or sticky this wait after firing the first side allows the clinker to cool and it contracts and will not stick to the grates as badly as when it is hot.

The second side is then broken up and pulled through the fire door in the same way and the good burning fuel scattered over the clean grate as before. Both sides are then fired, completing the operation. The doors should be open only when necessary and the cleaning done as quickly as possible.

The following method of cleaning fires is recommended by the Smoke Abatement Department of St. Louis. It has been successfully used in the University Power Plant, and when the directions are properly followed it produces less smoke than the ordinary method during the cleaning and immediately afterwards. It probably has very little effect upon the boiler and furnace efficiency:

"Do not clean out when fires are low, or when fresh fuel has just been added. Have a good bed of coal. Throw all the red fuel over on other side from one to be cleaned. Loosen up cinder with slice bar and pull out with hoe or rake. Break up coal to first size, and scatter four to six shovels on bare grates. Then throw hot coal back over fresh fuel on side that has been cleaned, and leave door ajar a minute or two. Wait for at least two firings before cleaning the second side, in the meantime firing somewhat heavier in front. See that the coal is incandescent, and proceed as with first side. Cleaning out in this manner will avoid making dense smoke, and will not lower the temperature of the boiler as much as the careless, usual way of cleaning fires."

Methods of Firing.

There are three methods of firing used in ordinary boiler practice, viz., **coking, spreading** and **alternate**.

In the **coking method,** after about all of the volatile matter is distilled off, the hot fixed carbon is pushed with a hoe to the back of the grate near the bridge wall. Here it makes a heap of bright, white-hot coals without smoke. Fresh coal is fired near the fire doors across the furnace, so that at all times the grate is covered with white hot coals at the back and green coal at the front.

The object sought for in this method is to distill the gases off of the green coal in front and to burn them while kept hot by passing over the hot bed of coals at the back. When the volatile gases are all driven off from the fresh coal in front leaving a bed of white hot coke, it is pushed back to replenish the hot bank in the rear and more fresh fuel is supplied at the front.

This method is seldom used in the Middle West. It is not an easy way of firing and is not suitable when large capacities are to be developed. It is often advised as a means of reducing smoke. There is a large loss of green fuel through the grates, and the frequent stirring of the fire tends to increase the clinker. The frequent opening of the fire doors increases the temperature stresses in the boiler and cools the furnace.

When this method of firing is used air should be admitted over the grate to help burn the volatile gases distilled from the green fuel.

The **spreading method** is the most commonly used method. It does not require as good a fireman or as much attention as the coking method.

Depending upon the size of the grate, two to six shovelfuls of coal are fired at a time, scattering the coal evenly over the grate. The fire is kept nearly level, a little thicker at the sides and back.

The fireman is apt to fire too much at a time or to fail to scatter the coal. If the coal is not well scattered, but each shovelful falls in one large mass, the fire will be cooled and deadened in spots. This causes uneven burning and the formation of holes. Holes are most likely to form at the sides and especially near the bridge wall. Fresh coal should not be used to fill up holes, but the fire should be leveled with a wide hook. All lumps should be broken up. Care must be taken not to dig in the fuel bed and stir up the ash with the hot live coals because this will increase the tendency to form clinker.

A good method of scattering the coal after the bed is level is to begin a strip at the back and scatter the coal over the strip while working to the front. A little practice will enable a good fireman to scatter a shovel full from the back to the front. Several of these strips will cover the entire grate.

The **alternate method** is much the same as the spreading method except that about one-half of the grate is fired at a time. For example, in a long line of boilers, the fireman goes down the line firing the first, third, fifth, etc., doors the first time, then making a second trip to fire the second, fourth, sixth, etc. The plan of firing in strips applies here as well as in the spreading method.

Where a three door furnace is used, the front half of the first and third doors and the back half of the second door are fired at one time. Then the next time the back half of the first and third doors and the front half of the second door are fired.

It is important that the fire be watched carefully and fresh fuel fed promptly, because the coke beds are apt to burn down letting an excess of air through. The object in leaving the coked bed is the same as in the coking method, the hot coke helps to burn the gases distilled from the fresh coal. Holes should be kept covered and the fire about level as in the other method.

In both the spreading and alternate methods of firing particular attention should be given to the scattering or sprinkling of the fresh fuel. Many firemen do not give this point care enough and it is very important. The practice of throwing the coal on the fire in heaps and firing enough to last fifteen or twenty minutes cannot be too severely condemned if high economy is desired. The fire is completely covered up and a dense cloud of smoke, indicating much unburned combustible, pours out of the chimney. Much of the fire is wasted and the firebed is left full of holes. If the coal is sprinkled over the fire, each lump separated from the others, the gases are exposed to the hot fuel bed and become well mixed with air. Good combustion then follows. In order to secure this result a few shovelsful frequently fired must be the rule. The importance of the length of time between firing has been mentioned in the first part of this bulletin. In general the shorter the firing interval the higher the efficiency and the less smoke. This is illustrated in Table IV, p. ...

The difference between a good and a poor fireman is usually due to the difference in the care and interest they have in their work, the difference in their skill in sprinkling the coal and keeping holes covered and in the frequent firing of small amounts of coal by the good fireman as compared to the fireman who piles in enough coal to last twenty minutes and then lets the fire burn full of holes.

Rules for Firing Using Illinois and Indiana Coal in Hand Fired Furnaces.

(Formulated by the Coal Stoking and Anti-Smoke Committee of the Illinois Coal Operator's Association.)

1. Break all lumps and do not throw any in furnace any larger than one's fist. The reason for this is, that large lumps do not ignite promptly and their presence also causes holes to form in the fire, which allow the passage of too much air.

2. Keep the ash pits bright at all times. If they become dark it is evident that the fire is getting dirty and needs cleaning, which, if not done, will cause imperfect combustion and smoke. If the furnace is equipped with a shaking grate, it should be opened often enough to prevent any accumulation of ashes in the fire. Do not allow ashes to collect in the ash pits, as they not only shut off the air supply, but may cause the grate to be burned.

3. In firing do not land the coal all in a heap, but spread it over as wide a space as possible as it leaves the shovel. A little practice will enable one to catch the proper motion to give the shovel to make the coal spread properly.

4. Place the fresh coal from the bridge wall forward to the dead plate and do not add more than three or four shovels at a charge. If this amount makes smoke it should be reduced till smoke ceases, which means, of course, that firing will be at more frequent intervals than formerly to keep up steam. This rule applies in cases

where the boiler is worked at a large capacity. In such instances, however, where a small capacity only is required, firing by the coking method is the best, wherein the fresh coal is placed at the front of the fire and pushed back and leveled when it has become coked.

5. Fire one side of the furnace at a time so that the other side containing a bright fire will ignite the volatile gases from the fresh charge.

6. Do not allow the fire to burn down well before charging. If this is done, it will not only result in a smoky chimney, but an irregular steam pressure.

7. Do not allow holes to form in the fire; should one form, fill it by leveling and not by a scoop full of coal. Keep the fire even and level at all times. As far as possible level the fire after the coal has become coked.

8. Carry as thick a fire as the draft will allow, but in deciding on the proper thickness, judgment must be exercised. If the draft is poor a thin fire will be in order, but if strong, a thicker fire should be carried.

9. Regulate the draft by the bottom or ash pit doors and not by the stack dampers, because when the stack damper is used it tends to cause a smoky chimney, as it reduces the draft, while the closing of the ash pit door diminishes the capacity to burn coal. If strict attention is given to firing, and according to demand for steam, there will be no occasion to have recourse to dampers, except where there is a sudden interruption in the amount of steam being used.

10. A good general rule is to fire little and often, rather than heavy and seldom. The former means economy in fuel and a clean chimney, while the latter signifies extravagance in fuel and a smoky chimney.

THE UNIVERSITY OF MISSOURI BULLETIN

NUMBER 9

ENGINEERING EXPERIMENT STATION
VOLUME 3 NUMBER 3

A REPORT OF STEAM BOILER TRIALS UNDER OPERATING CONDITIONS

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COLUMBIA, MISSOURI
September, 1912

INTRODUCTION.

Steam boiler trials may be divided broadly into two classes:

1. Tests under predetermined conditions, which are kept constant throughout, the purpose being to make a scientific study of the boiler performance under these conditions.

2. Tests performed under the every day operating conditions of the steam boiler plant.

Acceptance Tests.—These are made upon a new installation of boilers previous to their acceptance by the purchasers. They belong in class 1.

It is customary to include in a contract for steam boilers a number of clauses which carefully specify the minimum efficiency of combined boiler and grate when operating within a certain per cent of the rated power. Thus, it may be stated that, when burning bituminous mine run coal having a heating value of not less than 10,500 B. T. U. per pound, and operating between 80 and 120 per cent of the rated horsepower, the boiler shall absorb not less than 70 per cent of the calorific value of the coal.

In order to satisfy the purchaser that such a guarantee has been fulfilled, a boiler test must be made of not less than twelve hours duration. Commonly, the directions for the conduct of boiler trials comprised in the Standard Code of the American Society of Mechanical Engineers are followed. The boiler is fired up and operated for some time, in order to get the setting thoroughly heated up. Provision is made to dispose of surplus steam not needed in the operation of prime movers, so that the load, and all conditions, may be kept as nearly as possible constant. The firing is carefully supervised by the testing engineers representing the contractors and the purchasers. In some instances the coal is picked over and all slack and slaty coal thrown out. In short, every effort is made to get the best possible economy from the boiler on this test.

Tests Under Operating Conditions.—(Class 2). The conditions of every day service under which a boiler is operated are very different from those which obtain when an acceptance or similar test is run. Under every day operating conditions, the load on the boiler is likely to vary widely, from a very light load to a considerable overload, and sometimes these fluctuations follow each other rapidly. It is not practicable to maintain at all times the most advantageous test conditions.

The heating surfaces become coated with scale on one side and soot on the other, with the effect of decreasing the rate of heat transmission from hot gasses on one side of the surface to water on the other. Brick work is liable to crack, permitting air leakage; and if this air becomes heated in the furnace, later passing off at the flue temperature, a loss of heat results. In addition to these reasons for a lower efficiency than can be obtained under special test conditions, mention should be made of what are called "stand-by" losses. An individual boiler in a plant may or may not be operated twenty-four hours a day. In the great majority of cases, the working day is much less than twenty-four hours. In electric lighting plants it may be a short period of a few hours carrying the plant over the peak load of the day. When a boiler is to be cut out the fire must be banked, an operation which takes a certain amount of coal. Furthermore, the boiler and setting begin at once to sool off, and the steam pressure falls. When the boiler is to be gotten under steam again, a considerable amount of coal must be burned to heat up the boiler and its setting before it can begin to produce steam. It is clear that coal thus burned during the stand-by period should be added to that burned while producing steam to get the total fuel cost. The proportion of this stand-by loss to the coal burned to evaporate water will depend upon the relative lengths of time the boiler is under steam and banked.

Let C = weight of coal burned to produce steam.
Let C' = coal burned during stand-by period.
Let W = total weight water evaporated.
Let w = pounds of water evaporated per pound of coal burned.

Then the number of pounds of water evaporated per pound is, properly

$$w = \frac{W}{C + C'}$$

If, however, C' is not considered, our expression would become

$$w = \frac{W}{C}$$

It is clear from the foregoing arguments, why the economy of a boiler, in pounds of feed water per pound of coal, based upon monthly records of coal burned and water fed to boiler, is bound to be much below the figure found by an acceptance or similar test.

The boiler tests which form the basis of this bulletin, the results of which are summarized in tables I, II, III and IV, were made from time to time by students, under the writer's direction in the course of regular work in the Mechanical Laboratory at the University of Missouri. The boilers tested are located at the University heating and lighting plant, with the exception of the two tests of Table III, which were made on a Heine water tube boiler at the heating plant of the Horticultural Department.

The boiler equipment of the University heating and lighting plant consists of seven boilers, numbered consecutively, 1 to 7. Two of these, numbers 1 and 5, are Heine water tube boilers; the others are horizontal shell boilers of the return tubular type. Natural chimney draft is used for all. Boiler No. 1 is equipped with a rocking grate. The others have plain grates of the herring bone pattern. The tests herewith presented were made upon the two Heine boilers Nos. 1 and 5, return tubular boiler No. 7, and the Heine boiler before mentioned at the horticultural plant. The tests upon each boiler are comprised in a table, the short form of the A. S. M. E. Standard Code being followed. The heating surface, grate area, and rated power are given in each case.

In conducting these tests no effort was made to get an economy better than the ordinary daily performance. They represent ordinary operating conditions, but do not take into account stand-by losses.

The regular fireman fired the boiler in his customary manner. When the fire needed cleaning, he cleaned it, this operation usually taking place once or twice during the test. In case of the boilers with plain grates, most of the ash and refuse accumulates on the grate, and, in the process of cleaning, must be raked out through the door. This involves a considerable cooling of boiler and furnace, due to the admission of cold air, and a drop in the production of steam, disadvantages which are largely overcome by the use of a rocking grate, as in boiler No. 1. It was found in the tests on this boiler that nearly all the ash and refuse could be passed through by rocking the grate, though sometimes a few clinkers had to be raked out through the front door.

The method of starting and stopping was that defined in the Standard Code as the "Alternate Method." The procedure was as follows: The boiler being under steam, and the furnace and brickwork hot, the fire was burned low and cleaned. The pressure, temperatures, water level, and time of day were then noted, and the test was started. At the close the fire was burned low and cleaned, and the time of closing was considered to be the time when the operation of cleaning was concluded. An effort was made to have, as nearly as could be judgded from observation, the same amount of coal on the grate at the close as at the beginning. The water level in the boiler and the steam pressure were made the same as at the start.

The per cent of CO_2 in the flue gases was determined at frequent intervals by means of an Orsat apparatus. The gas was drawn from a point in the flue between the boiler and damper, through a ¼-inch pipe, by means of an exhauster, and a sample was drawn off into the Orsat instrument from the side outlet of a tee in the gas line.

The feed water was weighed in two tanks mounted on scales in the usual manner, and discharged thence into a third tank from which the feed pump or injector used to feed the boiler took its supply.

At the end of each hour an hourly balance was determined of the quantity of coal burned and water fed to the boiler; the average pressures and temperatures for each hour were also computed. In connection with tables I and II the records of hourly quantities of five of the tests are graphically shown, Figs. 1 to 5. These indicate the variations in the boiler load that took place from hour to hour, as the demand for steam fluctuated.

It will be noted that the stand-by losses which occur when the boiler is cut out are not included in the tests. The final results indicate about what may be expected during the working period in the way of economy, in an ordinary plant of small size, equipped with boilers of from 125 to 250 horse-power, burning western bituminous coal, and hand fired by firemen of mediocre ability.

The efficiency of boiler and grate combined, item 31, ranges from 43 to 60 per cent. Disregarding tests No. 2, Table I, and No. 6, Table IV, the range of efficiency is 47 to 57 per cent. The average efficiencies for each boiler, including grate (item 31) are as follows:

Boiler No. 1, Table I	46.1 per cent
" " " Omitting Test No. 2	47.6 " "
" " 5, Table II	51. " "
Hort. Boiler, " III	48.5 " "
Boiler No. 7, " IV	54.7 " "
" " " Omitting Test No. 6	53.8 " "

For the purpose of estimating the fuel expenditure for a given quantity of feed water delivered to a boiler, items 24 and 25 are of practical value to the owner and operator of a steam power plant who has not at hand the means of readily determining the per cent of moisture and ash in the coal, and hence cannot figure down to the basis of dry coal and of combustible, as in items 26 and 27. The maximum, minimum and average values of items 24 and 25 are arranged in the following summary. Also, to reduce the fuel cost to the basis of dollars and cents, another item (No. 33 of the short form) is added, assuming that the cost of coal delivered to the boiler room is $2.50 per ton of 2,000 pounds.

	Boiler No. 1	Boiler No. 5	Hort. Boiler	Boiler No. 7
	1	1	1	
Item 24.—Water apparently evaporated under actual conditions per pound of coal as fired. Maximum values	5.38	6.04	5.77	5.92
Item 24.—Minimum value	5.08	5.47	5.36	5.07
Item 24.—Average of all	5.18	5.72	5.56	5.53
Item 25.—Equivalent exaporation from and at 212 deg. per lb. of coal as fired. Maximum values	5.74	6.50	6.30	6.98
Item 25.—Minimum values	5.32	6.07	5.78	5.86
Item 25.—Average of all	5.54	6.29	6.04	6.47
Item 33.—Cost of coal required for evaporating 1,000 pounds of water from and at 212 degrees, coal at $2.50 per ton. Maximum value	$.235	$.206	$.216	$.213
Item 33.—Minimum value	.218	.192	.198	.179
Item 33.—Average of all	.225	.198	.207	.193

TABLE I.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Heine boiler No. 1, at U. of M. Heating and Lighting Plant.

Kind of fuel: Illinois coal.

Kind of furnace: Rocking grate, hand fired.

Method of starting and stopping: Alternate.

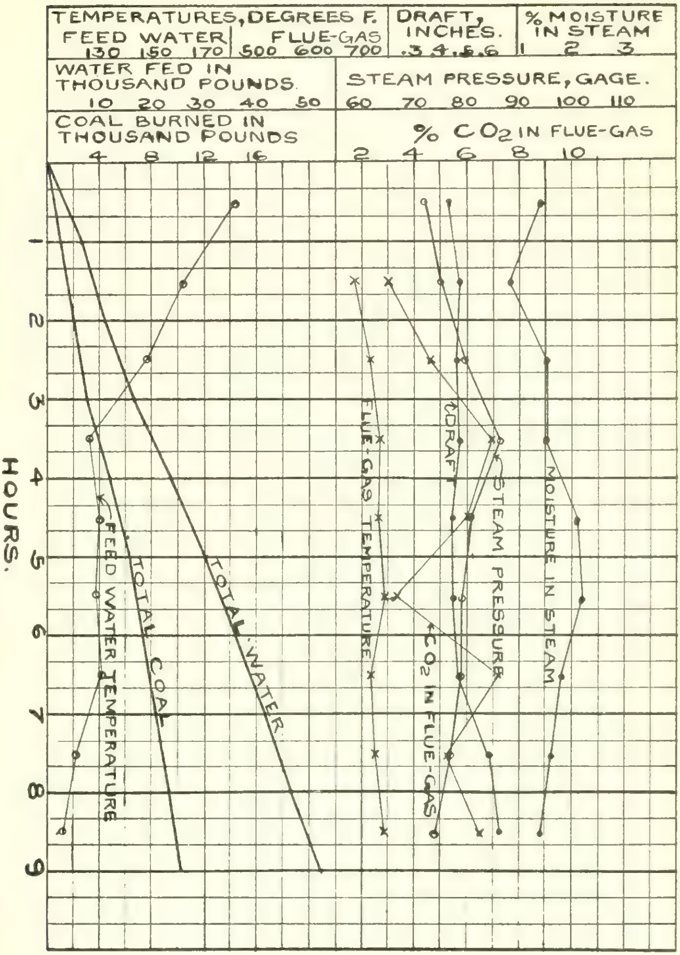
Grate surface: 40.5 square feet.

Water heating surface: 1399 square feet.

Total Quantities.	Test 1	Test 2	Test 3
1.—Date of trial	3/30, '12	4/13, '12	4/20, '12
2.—Duration of trial,hours	9	9.5	9.5
3.—Weight of coal as fired, pounds	10241	6200	6534
4.—Percentage of moisture in coal	9.52	8.32	6.98
5.—Total weight of dry coal consumed	9265	5685	6078
6.—Total ash and refuse, pounds	1588	685	838
7.—Percentage of ash and refuse in dry coal	17.15	12.3	13.7
8.—Total weight of water fed to the boiler, lbs.	52148	31482	35145
9.—Water actually evaporated, corrected for moisture in steam	51313	30850	34477
9a.—Factor of evaporation	1.110	1.069	1.087
10.—Equivalent water evaporated into dry steam from and at 212 degrees	56957	32980	37476
Hourly Quantities.			
11.—Dry coal consumed per hour, pounds	1029.5	599	639.7

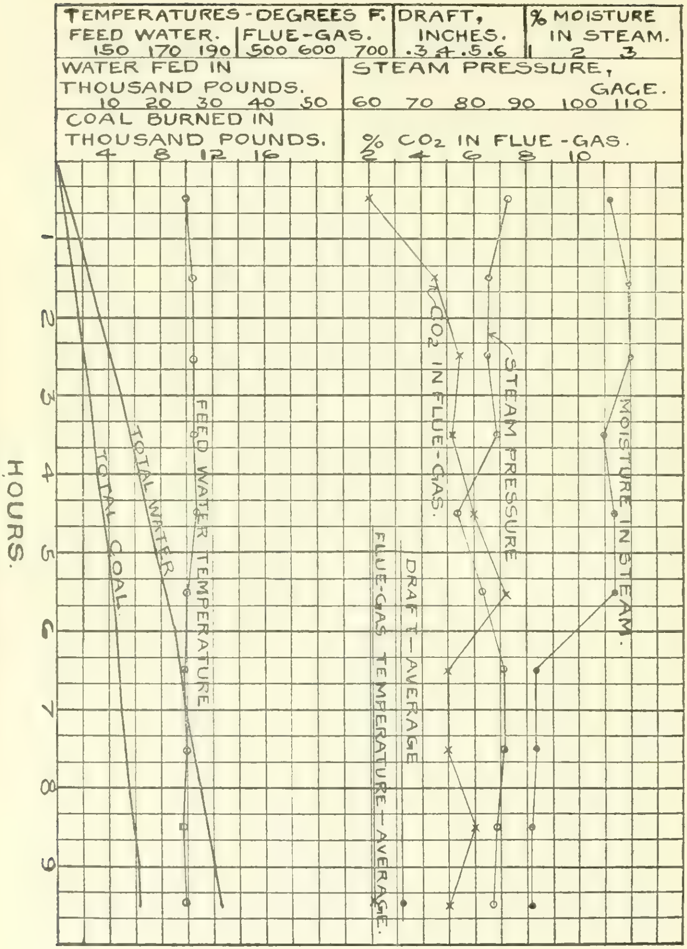
TABLE I.—Continued.

12.—Dry coal per sq. ft. grate surface per hour....	25.42	14.8	15.8
13.—Water evaporated per hour corrected for quality of steam	5700	3250	3629
14.—Equivalent evaporation per hour from and at 212 degrees	6329	3470	3944
15.—Equivalent evaporation per hour from at at 212 deg. per sq. ft. of water heating furnace..	4.52	2.48	2.82
Average Pressure and Temperatures.			
16.—Steam pressure by gage......................	78.5	83.3	85.11
17.—Lemperature of feed water, deg. F...........	138.5	181	163
18.—Temperature of escaping gas.................	726	705	702
19.—Force of draft between damper and boiler, inches of water............................	.49	.22	.24
20.—Percentage of moisture in steam.............	1.6	2.0	1.9
Horse-Power.			
21.—Horse-power developed	183	100.7	114
22.—Builder's rated horse-power.................	150	150	150
23.—Percentage of rated power developed.........	122	66	76
Economic Results.			
24.—Water apparently evaporated under actual conditions per pound of coal as fired........	5.09	5.08	5.38
25.—Equivalent evaporation from and at 212 degrees per pound of coal as fired...........	5.56	5.32	5.74
26.—Equivalent evaporation from and at 212 degrees per pound of dry coal................	6.15	5.80	6.17
27.—Equivalent evaporation from and at 212 degrees per pound of combustible.............	7.43	6.59	7.13
Efficiency.			
28.—Calorific value of the dry coal per pound, B. T. U.	12750	12940	12360
29.—Calorific value of the combustible per pound, B. T. U.	14390	14760	14750
30.—Efficiency of boiler based on combustible.....	50.1	43.15	47.0
31.—Efficiency of boiler, including grate, based on dry coal	46.8	43.25	48.4



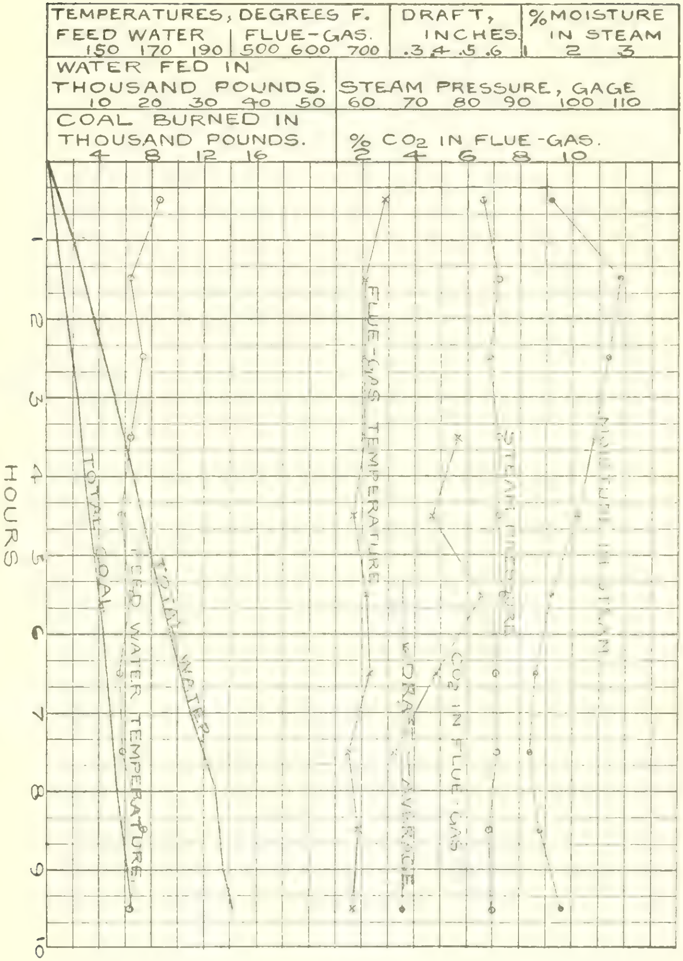
HEINE BOILER No. 1 — TEST No. 1

FIG. 1



HEINE BOILER No.1-TEST No.2

FIG. 2



HEINE BOILER, No. 1 — TEST No. 3

FIG. 3

TABLE II.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Heine boiler No. 5, U. of M. Heating and Lighting Plant.

Kind of fuel: Illinois coal.

Kind of furnace: Plain grate, hand fired.

Method of starting and stopping: Alternate.

Grate surface: 47 square feet.

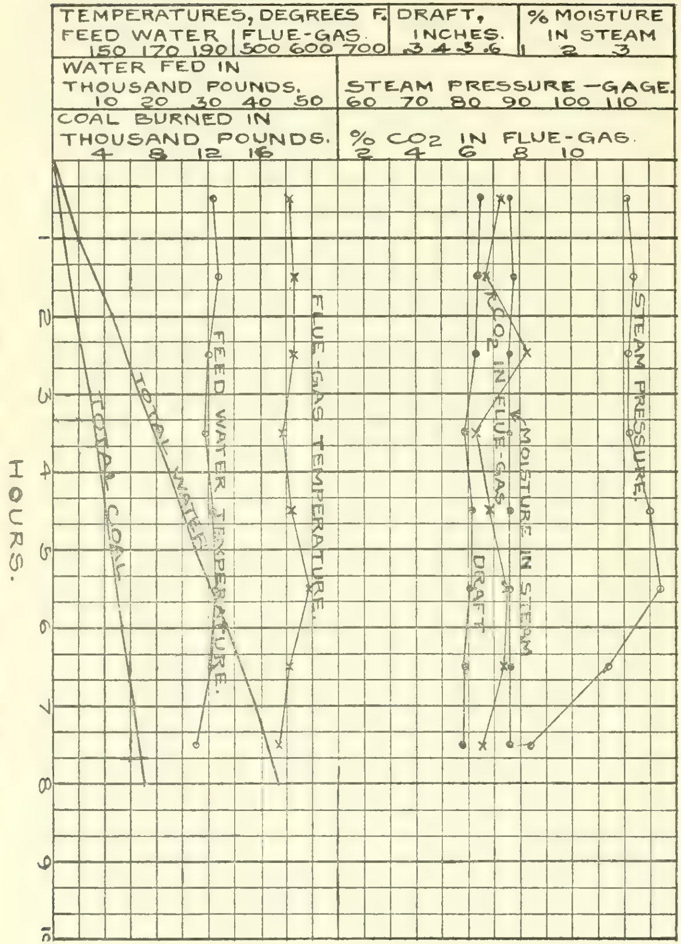
Water heating surface: 2232 square feet.

Total Quantities	Test 1	Test 2	Test 3	Test 4	Test 5
1.—Date of trial................	5/5, '09	5/6, '09	5/9, '10	4/27, '12	5/4, '12
2.—Duration of trial, hours....	8	8	8	8	10
3.—Weight of coal as fired, lbs.	7429	8121	9682	7183	9727
4.—Percentage of moisture in coal	7.4	11.0	9.6	5.97	7.84
5.—Total weight of dry coal consumed	6879	7227	8752	6754	8965
6.—Total ash and refuse, lbs...	1143	816	1564	966.5	1199
7.—Percentage of ash and refuse in dry coal................	16.65	11.3	17.9	14.3	13.4
8.—Total weight of water fed to the boiler, pounds.........	43912	45202	53000	43390	54504
9.—Water actually evaporated, corrected for moisture in steam	43692	44730	52310	43043	53926
9a.—Factor of evaporation......	1.107	1.130	1.121	1.061	1.138
10.—Equivalent water evaporated into dry steam from and at 212 degrees.............	48367	50545	58640	45670	61368
Hourly Quantities.					
11.—Dry coal consumed per hour, pounds	859	903	1094	844	896.5
12.—Dry coal per sq. ft. grate surface per hour, pounds..	18.26	19.22	23.2	18.0	19.06
13.—Water evaporated per hour, corrected for quality of steam	5461	5591	6540	5380	5392
14.—Equivalent evaporation per hour from and at 212 deg.	6046	6318	7330	5709	6137
15.—Equivalent evaporation per hour from and at 212 deg. per sq. ft. of water heating surface	2.70	2.82	3.28	2.40	2.74
Average Pressures and Temperatures.					
16.—Steam pressure by gage....	84	92.5	95.8	109.5	108.7
17.—Temperature of feed water,					

TABLE II.—Continued.

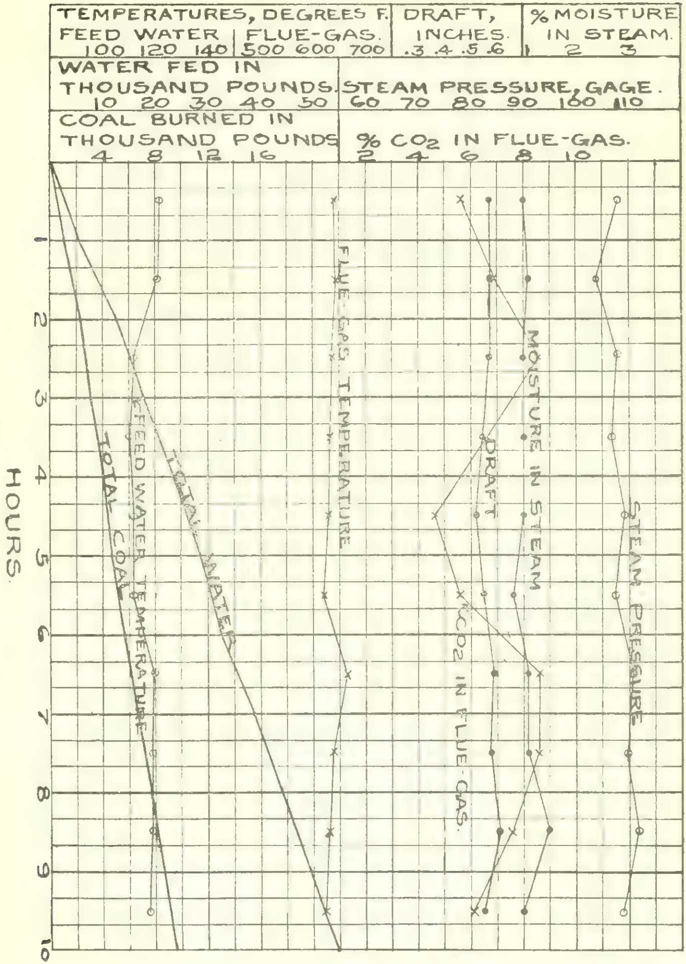
deg. F.	144	123	132	192	117
18.—Temperature of escaping gas.	515	512	609	563	637
19.—Force of draft between damper and boiler, inches of water	.42	.54	.67	.54	.57
20.—Percentage of moisture in steam	.49	1.05	1.30	.80	1.06
Horse-Power.					
21.—Horse-power developed	175	184	212	165	178
22.—Builder's rated horse-power.	250	250	250	250	250
23.—Percentage or rated power developed	70	73.6	84.8	66	71
Economic Results.					
24.—Water apparently evaporated under actual conditions per pound of coal as fired....	5.92	5.57	5.47	6.04	5.6
25.—Equivalent exaporation from and at 212 deg. per pound of coal as fired............	6.50	6.23	6.07	6.35	6.28
26.—Equivalent evaporation from and at 212 deg. per pound of dry coal...............	7.04	7.00	6.70	6.76	6.84
27.—Equivalent evaporation from and at 212 deg. per pound of combustible	8.43	7.89	8.17	7.88	7.90
Efficiency.					
28.—Calorific value of dry coal per pound, B. T. U.......	13970	*13900	12520	12413	12616
29.—Calorific value of the combustible per pound........	14700	......	14570	14000	14450
30.—Efficiency of boiler based on combustible	55.6	......	54.5	54.6	53.1
31.—Efficiency of boiler, including grate, based on dry coal..	48.9	48.8	52.0	52.8	52.6

*Assumed.



HEINE BOILER No. 5 — TEST No. 4

FIG. 4.



HEINE BOILER No. 5 — TEST No. 5.

FIG. 5.

TABLE III.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Heine boiler at Horticultural heating plant.
Kind of fuel: Illinois coal.
Kind of furnace: Plain grate, hand fired.
Method of starting and stopping: Alternate.
Grate surface: 25 square feet.
Water heating surface: 1217 square feet.

Total Quantities.	Test 1	Test 2
1.—Date of trial	2/19, '10	2/22, '10
2.—Duration of trial, hours	9	10
3.—Weight of coal, as fired, pounds	4647	5100
4.—Percentage of moisture in coal	7.9	7.9
5.—Total weight of dry coal consumed	4280	4700
6.—Total ash and refuse, pounds	1068	1031
7.—Percentage of ash and refuse in dry coal	24.9	21.9
8.—Total weight of water fed to the boiler, pounds	26769	27355
9.—Water actually evaporated, corrected for moisture in steam	26582	27000
9a.—Factor of evaporation	1.096	1.090
10.—Equivalent water evaporated into dry steam from and at 212 degrees	29181	29421
Hourly Quantities.		
11.—Dry coal consumed per hour, pounds	475	470
12.—Dry coal per square foot grate surface per hour	19.0	18.8
13.—Water evaporated per hour, corrected for quality of steam	2955	2700
14.—Equivalent evaporation per hour from and at 212 deg.	3242	2942
15.—Equivalent evaporation per hour from and at 212 deg. per square foot of water heating surface	2.64	2.43
Average Pressures and Temperatures		
16.—Steam pressure by gage	44	65.3
17.—Temperature of feed water, deg. F.	144	156
18.—Temperature of escaping gas	574	646
19.—Force of draft between damper and boiler, inches of water	.34	.38
20.—Percentage of moisture in steam	.70	1.3
Horse-Power.		
21.—Horse-power developed	94	84
22.—Builder's rated horse-power	130	130
23.—Percentage of rated power developed	72.5	64.8
Economic Results.		
24.—Water apparently evaporated under actual conditions per pound of coal as fired	5.77	5.36

TABLE III.—Continued.

25.—Equivalent evaporation from and at 212 deg. per pound of coal as fired	6.30	5.78
26.—Equivalent evaporation from and at 212 deg. per pound of dry coal	6.82	6.26
27.—Equivalent evaporation from and at 212 deg. per pound of combustible	9.06	8.03
Efficiency.		
28.—Calorific value of dry coal per pound, B. T. U.	13184	12880
29.—Calorific value of combustible per pound	......	......
30.—Efficiency of boiler based on combustible	......	......
31.—Efficiency of boiler, including grate, based on dry coal	50.0	47.1

TABLE IV.

DATA AND RESULTS OF EVAPORATIVE TESTS.

Name and location of boiler: Return tubular, No. 7, U. of M. heating and lighting plant.
Kind of fuel: Illinois coal.
Kind of furnace: Plain grate, hand fired.
Method of starting and stopping: Alternate.
Grate surface: 25.3 square feet.
Water heating surface: 1239 square feet.

Total Quantities.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
1.—Date of trial	2/11, '11	2/25, '11	3/11, '11	4/1, '11	4/8, '11	4/22, '11
2.—Duration of trial, hours	10	9	10.23	10.06	10	10
3.—Weight of coal as fired, pounds	7957	8446	7658	8125	7379	7640
4.—Percentage of moisture in coal	9.0	12.0	8.4	9.4	8.9	9.5
5.—Total weight of dry coal consumed	7240	7430	7015	7360	6720	6914
6.—Total ash and refuse, pounds	1120	1348	1135	1128	1093	1157
7.—Percentage of ash and refuse in dry coal	15.5	18.1	16.2	15.3	16.2	16.8
8.—Total weight of water fed to the boiler, pounds	46506	42866	42313	44706	43673	40950
9.—Water actually exaporated, corrected for moisture in steam	45395	42350	42059	44350	43200	40377
9a.—Factor of evaporation	1.188	1.170	1.164	1.191	1.193	1.192
10.—Equivalent water evaporated into dry steam from and at 212 degrees	53923	49549	48956	52820	51537	48129
Hourly Quantities.						
11.—Dry coal consumed per hour, pounds	724	825	685	731	672	691
12.—Dry coal per sq. ft. grate surface per hour	28.5	32.5	27.1	28.8	26.6	27.2
13.—Water evaporated per hour, corrected for quality of steam	4539	4705	4110	4408	4320	4038
14.—Equivalent evaporation per hour from and at 212 degrees	5392	5506	4785	5250	5154	4813
15.—Equivalent evaporation per hour from and at 212 deg. per sq. ft. of water heating surface	4.35	4.44	3.86	4.23	4.16	3.88

TABLE IV.—Continued.

Average pressures and Temperatures.						
16.—Steam pressure by gage	93.6	90.4	96.7	94.8	92.2	96.7
17.—Temperature of feed water, deg. F.	67	83	90	64	62	63
18.—Temperature of escaping gas	560	547	522	472	521	485
19.—Force of draft between damper and boiler, inches of water.	.73	.50	.46	.54	.53	.56
20.—Percentage of moisture in steam	2.4	1.2	.6	.8	1.1	1.4
Horse-Power.						
21.—Horse-power developed	156	160	139	152	150	140
22.—Builder's rated horse-power	150	150	150	150	150	150
23.—Percentage of rated power developed	104	106.6	92.6	101.3	100	93.3
Economic Results.						
24.—Water apparently evaporated under actual conditions per pound of coal as fired	5.84	5.07	5.52	5.50	5.90	5.36
25.—Equivalent evaporation from and at 212 deg. per pound of coal as fired	6.77	5.86	6.39	6.51	6.98	6.30
26.—Equivalent evaporation from and at 212 deg. per pound of dry coal	7.44	6.67	6.97	7.18	7.67	6.97
27.—Equivalent evaporation from and at 212 deg. per pound of combustion	8.81	8.16	8.32	8.47	9.16	8.38
Efficiency.						
28.—Calorific value of dry coal per pound, B. T. U.	12840	13190	12800	*13000	*13000	11380
29.—Calorific value of the combustible per pound	14600	14800	14350	15100	14750	14070
30.—Efficiency of boiler based on combustible	58.5	53.5	56.2	54.3	60.2	58.0
31.—Efficiency of boiler including grate, based on dry coal	56.2	49.1	52.8	53.7	57.2	59.6

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*Assumed.

It will be noted that the boiler efficiencies in these tests are somewhat lower than those commonly found in similar boilers under test conditions. At the Louisiana Purchase Exposition in 1904 a large number of tests were made at the coal testing plant that was operated for the purpose of investigating the qualities of the various coals and lignites of the United States, the results of which are found in the published "Report on the Operations of the Coal Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, 1904." Heine Saftey boilers of 210 horse-power rated capacity were used. The grates were plain, the furnace hand fired and the draft natural. For purposes of comparison, the results of tests Nos. 18, 19, 38, 48, 50, 73, in which series Illinois coal was burned, are summarized, together with the tests of Table II, Heine boiler No. 5, in Table No. V, which follows. The data of the St. Louis tests are taken from the Report, p. 961. It will be note dthat the economic results, items 26 and 27, from Table No. II, are about 9 per cent less in amount than the corresponding figures for the St. Louis tests; while the two efficiencies, items 30 and 31, are respectively 10 and 14 per cent lower.

TABLE V.

A comparison of Economic Results and Efficiencies between Heine boiler No. 5, Table II, and tests made at the Louisiana Purchase Exposition, St. Louis. Illinois coal used in both series.

		Economic Results.				Efficiency (per cent).			
	Test Number.	Water apparanently evaporated under actual conditions per pound of coal as fired.	Equivalent evaporation from and at 212 deg. per pound of coal as fired.	Equivalent evaporation from and at 212 deg. per pound of dry coal.	Equivalent evaporation from and at 212 deg. per pound of Combustible.	Calorific value of dry coal per pound, B. T. U.	Calorific value of the combustible per pound, B. T. U.	Efficiency of boiler based on combustible.	Efficiency of boiler including grate, based on dry coal.
		24	25	26	27	28	29	30	31
St. Louis Tests.	18	5.54	6.51	7.21	8.76	11,855	14,252	59.36	58.73
	19	6.09	7.16	8.00	8.92	12,569	14,159	60.83	61.47
	38	6.19	7.35	8.04	9.53	12,857	14,712	62.42	60.39
	48	5.39	6.38	7.37	8.61	12,427	14,323	58.05	57.27
	50	5.34	6.36	7.27	8.44	12,439	14,319	56.92	56.35
	73	5.32	6.43	7.40	8.75	11,594	13,992	60.39	61.64
	Average	5.56	6.70	7.55	8.84	12,293	14,293	59.66	59.31
Table No. II.	1	5.92	6.50	7.04	8.43	13,970	14,700	55.60	48.90
	2	5.57	6.23	7.00	7.89	13,900	......	....	48.80
	3	5.47	6.07	6.71	8.17	12,520	14,570	54.50	52.00
	4	6.04	6.35	6.76	7.88	12,413	14,000	54.60	52.80
	5	5.60	6.28	6.84	7.90	12,616	14,450	53.10	52.60
	Average	5.72	6.28	6.87	8.05	13,084	14,430	53.56	51.02

THE
UNIVERSITY OF MISSOURI
BULLETIN

ENGINEERING EXPERIMENT STATION SERIES
VOLUME IV NUMBER 1

ECONOMICS OF RURAL DISTRIBUTION OF ELECTRIC POWER

BY

L. E. HILDEBRAND

MDCCCXXXIX

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
March, 1913

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1st, 1909.

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First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

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The staff of the Station consists at present of a Director and one research assistant together with a number of teachers who have undertaken research under the direction of the Station.

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PREFACE.

This bulletin is intended to be of interest to three classes of people; farmers, central station managers and engineers concerned with rural distribution of electric power. While all parts may not be clear to all three classes yet it is believed that the bulletin as a whole will be well understood by all if the few technical discussions are assumed to be correct. The entire paper is primarily a discussion of the economic problems of rural distribution rather than a handbook of rural electrical construction and practice.

We have, in the preparation of the manuscript, freely consulted the various technical periodicals and the reports of the various engineering societies. Much valuable information has been obtained from the **Electrical World, The Electrical Review and Western Electrician, The Proceedings of the American Institute of Electrical Engineers** and the **Proceedings of the National Electric Light Association.** Various text books of electrical engineering such as Sheldon, Mason & Hausmann's **Alternating Current Machines,** Franklin & Esty's **Elements of Electrical Engineering,** Steinmetz's **Alternating Current Phenomena,** Foster's **Electrical Engineering Pocket Book;** and the catalogues and bulletins of General Electric Company, Westinghouse Electric & Manufacturing Company, Western Electric Company, American Steel & Wire Company, and Central Electric Company, have been freely used.

We wish to thank Messrs. M. P. Weinbach, E. W. Kellogg and S. M. Hardaway for valuable assistance in correcting the manuscript and for general advice.

LEE E. HILDEBRAND.

University of Missouri,
Columbia, Missouri,
December 18, 1912.

INTRODUCTION.

Within the past few years there has developed a persistent desire in the mind of the American farmer for the conveniences of urban life. Throughout the country we find many instances of the gratification of this desire in the extended use of the comforts which a few years ago were considered luxuries on a farm. The rural mail delivery connects the farm daily with the entire outside world; the telephone keeps the farm continuously in touch with the immediate community while good roads promote both the business interests and the social intercourse of the rural population. The present large use of these and many other conveniences has made rural life more desirable and has lessened the migration of our farmers, and farmers' sons and daughters to the cities. At the present time we find everywhere the idea that city comforts should be brought to the farmer and not the farmer to the city conveniences.

Electricity on the Farm.—Among the various sources of comfort and convenience to be found in large towns and cities is the use of electricity for lighting, household purposes and power. The use of electric power in rural districts can and should be extended largely as it is a direct means of effecting a large saving of both money and time. Farmers realize the necessity of using labor saving devices. This more than any other factor has caused the large increase in the use of gasoline engines on farms. This bulletin is a discussion of a substitute for the gasoline engine which is as cheap if not cheaper than the engine, everything considered. It is not intended to depreciate the usefulness of a gasoline engine as it is indeed almost indispensible in some places, but rather to show a better means of obtaining mechanical power.

There is no doubt but that wherever possible it is generally preferable to employ power to do a certain task rather than to use manual labor. There are few at the present time who deny that electric power is the safest, most convenient and most economical means of doing work, if the electric power is obtainable at a fair price, but obtaining the power is often the stumbling block in the way of using electricity in rural regions. It must be shown that its conveniences and economy are so great that it would be wise, economical and expedient to distribute electricity for lighting and power to the rural districts.

Advantages of Electricity for Lighting.—Except those engaged in the sale of gas or gas-lighting fixtures, few deny that the electric incandescent lamp is the safest and most convenient means of illuminating residences that has yet been discovered. This statement is confirmed by its extensive use in all cities where electric power is obtainable. How many times have you seen advertisements for hotels, apartment houses and residences for rent, which state as an added inducement, "Electric Lights" or "Thoroughly wired for electric light"? The number of large buildings without electric light is extremely small and most of the smaller ones have complete equipments if electricity is obtainable at a reasonable rate.

There are a number of desirable qualities possessed by the electric light which are not to be found with any other illuminant. When a house is wired in accordance with the present standards, the fire risk can be considered as negligible, whereas with any lamp which depends on an open flame for its incandescence and a match for its ignition there is always some danger of fire. The number of fires caused by matches which are not extinguished when thrown away, possibly on a carpeted floor or in a waste basket, is certainly large. The danger of an accident with the ordinary portable kerosene lamp is especially large. Electric light is safest and most convenient since it is only necessary to turn a switch to instantly flood the room with light. The electric light is not dirty and requires extremely little attention. Contrast this with any other known source of light and the relative merits of the different illuminants are easily seen. Since the electric lamp operates in a closed bulb and very little heat is thrown off, it is easy to see that, in winter when the rooms are more or less closed, the ventilation will be much better, and in summer the rooms will be cooler. There are other advantages, too numerous to mention in this paper, which make electric lighting universal where power is obtainable.

Household Use of Electricity.—There are many operations in the daily routine of housekeeping in which a small amount of power conveniently applied would be very advantageous. A small motor can be used to operate the washing machine or the sewing machine, to clean the room by means of a vacuum cleaner, to pump water, to clean and polish the silverware and even to wash the dishes. These tasks and many others which can be easily and expeditiously performed by electric power, are the ones which keep the housekeeper busy from morning until night, whereas, if a small motor is used, some leisure time is afforded for relaxation and the actual labor is made very much lighter. The electric flat iron is in daily use in thousands of homes, making ironing day very much less disagreeable. There are many electric heating and cooking devices on the market which find appreciative users in all parts of the country. A few of these devices are coffee percolators, toasters, chafing dishes, frying pans, ovens, curling irons, water heaters, shaving mugs, small heaters for halls and bathrooms, and glue pots. Some of these would undoubtedly be useful in rural homes.

Farm Motors.—A large motor can be used by the farmer in many operations which now require manual labor or the use of a gasoline engine. Grinding feed, cutting ensilage, pumping water for live stock or for irrigating during drouth, sawing wood, baling hay, threshing and many other tasks of similar nature are easily, quickly and cheaply accomplished by the use of an electric motor.

The farmer will say at once, "Can not all these things be done with a gasoline engine?" They can, but a motor possesses many advantages over the engines usually found on a farm. It is no trouble to start a motor—just close a switch and the machine is in operation. We all know the amount of trouble and exertion required to start a gasoline engine, especially in cold weather. If a motor is used there is no cooling water to attend to or to keep from freezing and no dangerous supply of gasoline is required which will be constantly wasted by evaporation. Ignition troubles are entirely absent. The first cost of a motor is lower than that of a high class engine and the yearly repair bills are very much less. A motor is always ready to give reliable and steady service at any time and at large overloads with high efficiency, whereas an engine must be in first class condition to deliver even its normal full load rating. Less space is required for a motor than for an engine. Insurance is always high on any building containing a gasoline engine while the proper installation of a motor will not affect the rates. A motor continues to give satisfactory, reliable and cheap service, with only a small supply of oil a few times a year long after two engines have been discarded. The popularity of the motor is due particularly to its cheapness but mostly to its ease of application, operation and control.

This comparison is not made to show the faults of the gasoline engine, but rather to show the many good qualities possessed by electric motors. Gasoline engines can not be recommended too highly for farm use where electric service is not available. Any task which an electric motor can perform, can also be done by an engine, but with less convenience, more trouble and, quite often, greater expense. If the advantages of using a gasoline engine on the farm are admitted, it follows that an electric motor would be even more advantageous.

Costs of Farm Operations.—Table 1 gives the cost of performing many farm operations with electric power at various rates. The

TABLE 1

Operation	Remarks
Grinding corn	Large grinder, about 40 bu. per hour
Grinding corn	Small grinder, about 10 bu. per hour
Threshing barley	
Cutting ensilage	6 tons per hr. cut and elevated with blower
Husking	4 bu. per hr.
Grinding feed	one ton per hr. of heavy grains
Shredding fodder	2 tons per hr.
Clover cutting	41 lbs. per hr. finely cut—90 coans
Milking	30 qts. per hr.
Corn sheller	26.5 bu. per hr.
Washing	⅛ hp. motor per washer full
Sawing wood	4 cords per hr.
Pumping water	72 gallons per hr.
Threshing rye, wheat, oats, barley	
Washing	¼ hp. motor per washer full
Shredding and husking corn.	6 wall 3 header and husker
Vacuum cleaner	per 100 sq. ft. carpet or rug
Horse groom	1 hp. motor
Cream separator	
Butter churn and worker	
Sausage grinder	large
Sausage stuffer	⅜ hp. motor
Beet and turnip cutter	6 tons per hr.
Rolling oats	25 hp. mill
Cracking corn	
Oat crusher	
Milking	

figures are from various sources, most of them being obtained from tests under actual operating conditions, the results of which have been published in the several engineering magazines and reports of the engineering societies. No attempt has been made to substantiate these results except to give them a superficial examination. They are not intended to be used for the calculation of costs with any and all types of machines on the market, but rather to give a fair idea of the cost of doing some farm tasks with electric power.

TABLE 1

Unit	KW hrs.	Cents per Unit at following cost of power in cents per K. W. hour.						
		4	5	6	8	10	15	20
bu.	.4	1.6	2.	2.4	3.2	4.	6.	8.
bu.	.8	3.2	4.	4.8	6.4	8.	12.	16.
bu.	.125	.5	.625	.75	1.	1.25	1.875	2.5
ton	.66	2.64	3.3	3.96	5.28	6.6	9.9	13.2
bu.	.105	.42	.525	.63	.84	1.05	15.75	2.1
100 lbs.	.66	2.64	3.3	3.96	5.28	6.6	9.9	13.2
ton	5.5	22.	27.5	33.	44.	55.	82.5	110.
100 lbs.	.87	3.48	4.35	5.22	6.96	8.7	13.05	17.4
qt.	.004	.016	.02	.024	.032	.04	.06	.08
bu.	.028	.112	.14	.168	.224	.28	.32	.64
.. ..	.023	.092	.115	.138	.184	.23	.345	.46
cord	1.25	5.	6.25	7.5	10.	12.5	18.75	25.
hr.	.5	2.	2.5	3.	4.	5.	7.5	10.
bu.	.22	.88	1.1	1.32	1.76	2.2	3.3	4.4
.. ..	.061	.244	.305	.366	.488	.61	.915	1.22
tons	5.37	21.48	26.85	32.22	42.96	53.7	70.55	107.4
.. ..	.023	.092	.115	.138	.184	.23	.345	.46
horse	.106	.424	.53	.636	.848	1.06	1.59	2.12
100 lbs.	.04	.16	.2	.24	.32	.4	.6	.8
lb.	.0006	.0024	.003	.0036	.0048	.006	.009	.012
100 lbs.	.44	1.76	.22	.264	.342	4.4	6.6	8.8
100 lbs.	.05	.2	.25	.3	.4	.5	.75	1.
ton	.158	.632	.79	.948	1.264	1.58	2.37	3.16
bu.	.06	.24	.3	.36	.48	.6	.9	1.2
bu.	.1	.4	.5	.6	.8	.1	1.5	2.
bu.	.2	.8	1.	1.2	1.6	2.	3.	4.
can	.02	.08	.1	.12	.16	.2	.3	.4

The cost of energy for motor service on most farms will be between 4 and 8 cents per kilowatt hour, so these are the figures which should be taken for comparison in most places. Only the actual cost of energy is considered and all such charges as interest, depreciation, repair and taxes are omitted. This is the basis on which such work is usually compared.

Motors for general farm use are quite often mounted on skids or trucks so that they can be moved from place to place easily. The truck should have mounted on it not only the motor, but also a switch, a fuse for each wire and any starting device which is required. Fig. 1 shows a small motor mounted on skids with its fuses and switch on a small upright board. Fig. 2 shows a large motor placed on a truck. If the motor is large enough to require a starting device it can be placed just behind the small switchboard.

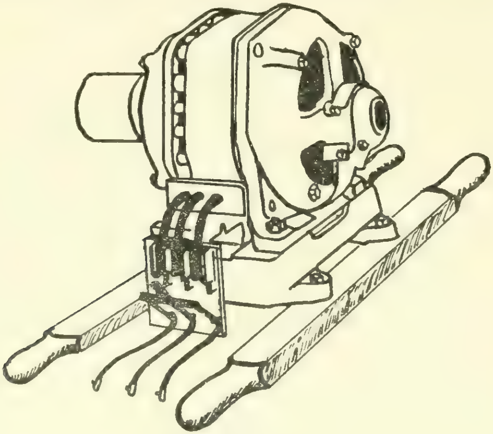


Fig. 1.

Development of Rural Use of Electricity.—Within the past few years we find a remarkable development in the use of electricity in rural districts for both light and power. The progress has proceeded most rapidly in the more thickly settled communities in the states of the Mississippi valley. However, there is a greater aggregate of power used in the arid western states. In the central states, electric power is already used for performing almost every operation of farm life which requires power, while large tracts of land in the western states are made productive by irrigation with electrically driven pumps when otherwise they would be sandy wastes. Ohio, Illinois, Michigan and Indiana have numerous installations of transmission lines serving rural districts. Some western water power plants depend to a large extent for their income upon the power sold to ranchers for irrigation purposes.

The development has proceeded even further in Enropean districts. In Italy and Germany are to be found many interesting installations, the power even being used for tilling the fields very much as we use a steam or gasoline traction engine. A complicated construction is used to deliver electric power to the tractor through a system of cables. The system used is very expensive, but the results obtained more than compensate for the expense, so that the use of electric power is made economical even in the complicated system used for tillage. If this use of electric power has proved economical when we take into account the difficulties and the elaborate apparatus required, how much more would the use of electric power for stationary machines with very simple installations, prove advantageous? Americans have boasted of progressiveness for so long that we are rather inclined to believe that we are first in all things, but here is one matter in which Europeans are far ahead of us. These countries are more densely populated than the United States in the rural districts; this accounts for some of our lack of development. American rural communities are now rapidly improving in this respect and many farms where the work is done by the efficient electric motor are to be found. When the great convenience of the electric power and the service which the motor will give at a cost lower in most cases than that of other kinds of power which are available to farmers are considered, we can predict great progress in the use of electric power on farms during the next few years. All engineering magazines have articles on this subject from time to time, and central station managers are beginning to consider this field seriously as a means of extending their business. In fact there are few power systems in the western states which do not have considerable load consisting of motors connected to pumps for irrigation purposes; and a few derive the major portion of their income from farming communities.

Reasons for Development.—In the early days of electric power the more densely populated districts of large cities were the first markets to be developed, as a greater number of customers could be reached with little capital. As there were plenty of customers to be found in cities, the greater effort was exerted to obtain those from whom the largest profit could be derived with the least investment. Now that nearly all of the people of this class who will ever use electricity are already paying customers, an effort is being made to secure those customers from whom a fair profit can be derived, but who are harder to serve. One class of these customers is composed of factory power users, who are hard to serve because they require reliable and continuous power at a very low rate. Another class consists of those customers who are users of but little energy, and who are far from the central plant.

The remoteness of farmers from stations has kept the development of rural distribution of electric energy in the rear for some time, but now that the possibilities of the large field for extension with prospects of fair returns is realized, more effort is being made to secure these many thousands of customers who were once thought to be entirely outside the zone of practical and economic distribution.

That it is both possible and profitable for central electric stations to extend service to at least some of the farmers can be seen by considering the fact that a large number of "**off peak**" customers can be served from a relatively cheap line with voltages very seldom above 6600. It is the fact that the farmers will furnish a good day motor load which makes them particularly desirable customers.

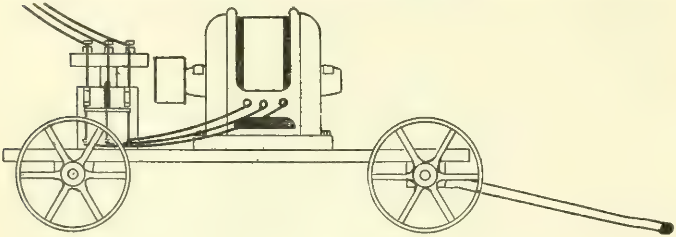


Fig. 2.

It should not be hard for the farmer to see the desirability of using electric power when the many advantages and the low cost are considered. The central station man will see the advantages of serving these customers in those cases where the cost of construction of the line can be kept low enough to make the distribution of a small amount of power at a low unit cost profitable to the station. We shall therefore proceed to investigate the distribution of power in farming districts keeping before us at all times the economic side of the question.

Securing Electric Power on Farms.—Electric power can be made available in almost any rural district, but it is not always economical or practical to use electric power, especially in very thinly settled communities, and where each customer uses a very small amount of power. Most cases will need the exercise of considerable judgment to secure the best and most economical installation when more than one type of installation is feasible. In other cases it will require much consideration to determine whether or not an installation of any type is feasible. The various localities, having materially different conditions, necessarily present entirely different problems for solution. The amount of power used, measured in kilowatt hours per year per mile of line, is a factor in the selection of the system. Thus if there are four customers per mile, and each customer uses 2000 kilowatt hours per year there would be 8000 kilowatt hours sold every year for each mile of line. Under these conditions it might be feasible for a central electric power plant to install a distribution system; whereas if the customers are so far apart that only 1000 kilowatt-hours would be sold per year for each mile of line it would be impracticable to install a transmission line. In the case of a few isolated customers each one of whom use a fair amount of power, a separate plant for each farm is necessary.

Thus it appears that there are two sources of electric power for the farmer: first, isolated plants, and second, distribution systems from central electric plants. The former usually consists of a small generator driven by an internal combustion engine, continuity of service being obtained by the use of a storage battery to deliver stored energy when the engine and generator are not in operation. The second source includes distribution lines built from the near by plants, either by the cooperation of the farmers, or by the station itself; distribution lines supplied from high voltage transmission lines; and distribution lines from centrally located power plants for farmers only, such as are found in Germany. Each of these different phases of the problem will be studied separately in different parts of this bulletin.

Isolated Plants.—When a farmer desires electric service and when he is the only one in the community who wishes to use electric power, the isolated plant is the only solution, unless he is able to furnish an extremely large load. In the case of the isolated plant, a gasoline or oil engine is used to drive a small direct current generator which charges a storage battery, the energy for lighting and power being taken from the battery, or the battery and generator combined. Power can be obtained from the battery at all times, while the plant need be operated only occasionally for a few hours at a time. The number of hours that it will be necessary to use the engine and generator will of course depend entirely on the amount of energy that is used, as the battery has only a limited capacity, and must be charged frequently by the generator. This installation is suitable for supplying a small amount of power only, and is best adapted to lighting and household use, although power motors may be used if desired.

Most installations of this character use a one or two horsepower engine, with a one-half or one-kilowatt generator, and a storage battery which will store sufficient energy to light from 10 to 25 tungsten lamps, of 16 candle power each, continuously for 8 hours. If fewer lamps are used the battery charge will last longer. Therefore the average farm house can be lighted from three to seven days without the engine being used. A three horsepower motor can be used about two hours on the larger plant taking its power from the engine and battery together, but the power which can be used continuously is less than that of the engine, in most cases only about one-half, because it is only the stored energy in the battery which makes it possible to use the large motor even for a short time. The small isolated plant is intended to be used only for lighting purposes. There is little advantage in using a gasoline engine to drive a generator which would in turn operate the motor, when the engine itself could be used to drive the machine, obtaining more power for the same expenditure by eliminating the losses in the transmission line and motor. If an isolated plant is to be installed, a portable engine should be purchased so that it can be used for other power work, and the electric power be used for lighting only. There is no doubt that an isolated plant will give satisfactory service if a reasonable amount of attention is given to it, but the cost is liable to be very high for the service rendered. The operating expenses are seldom excessive, but the fixed charges such as interest on the investment and depreciation of the machine make the overall expense high. From the standpoint of cost, an isolated plant compares favorably with the other means of obtaining light on the farm, such as acetylene or gasoline outfits, and about the same amount of attention is required for satisfactory operation. However electric light has several advantages which make it more desirable. No system therefore, can be recommended in preference to the others, but the cost and service rendered by each must be considered in every case.

A Typical Isolated Plant.—As an example of what may be expected from isolated plant installations we give two examples of typical plants. The first plant described is a small one for lighting only, while the second is larger and has some advantages not included in the first. Figure 3 shows the general appearance of the small outfit while figure 4 shows a diagram of electrical connections.

The initial cost of the apparatus is approximately as follows:

Switchboard	$ 65.00
Engine, 1 horsepower	90.00
Generator ½ kilowatt at 50 volts	85.00
Belt, foundation, piping, etc	25.00
Battery 40 ampere hour, 16 cells	85.00
	$350.00

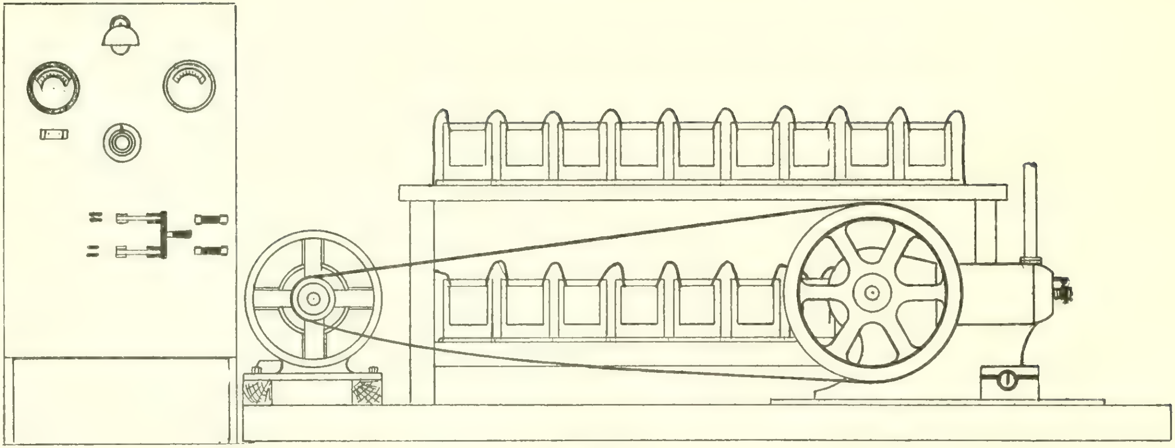


Fig. 3.

The cost of installation has been omitted as the plant can be set up by the farmer himself in his spare time. An expert wireman can make the electrical connections for the plant in a day. The cost of wiring a six room house, including two lamp fixtures in two rooms and pendent lamps in the other rooms and on the porches, with flush switches on the wall to control the lamps will be about $50.00. The total cost of the installation is then $400.00.

If fully charged at the start the battery will supply lamps with energy as shown in Table 2.

TABLE 2.

Hours	Number of 16 C. P tungsten lamps	Number of 16 C. P. carbon filament lamps
3	15	5
4	12	4
6	9	3
8	8	3
10	7	2

A six room house could probably be lighted two or three days without recharging the battery. It takes eight hours to charge the battery, so that the engine need be operated only about 3 hours per day or eight hours every two or three days.

The annual cost of operation is as follows:

Interest, $400 at 6%	$24.00
Depreciation of engine and battery, $175 at 10%	17.50
Depreciation of other equipment, $225 at 5%	11.25
Lamp renewals	5.00
Gasoline, oil and supplies	20.00
Repairs and taxes, $400 at 2%	8.00
	$85.75

The cost of light per month is $7.15. In the above calculations we have assumed that no motors are to be used. It is perhaps unfair to charge all the investment costs of the engine to the lighting installation as the engine can and probably will be used for other purposes. Again the fire insurance on the buildings that have electric lights would probably be reduced so that the cost of light may be reduced on this account. However we do not believe that it is possible to light a country residence with an isolated electric plant for less than $5.00 per month when all the cost factors are considered.

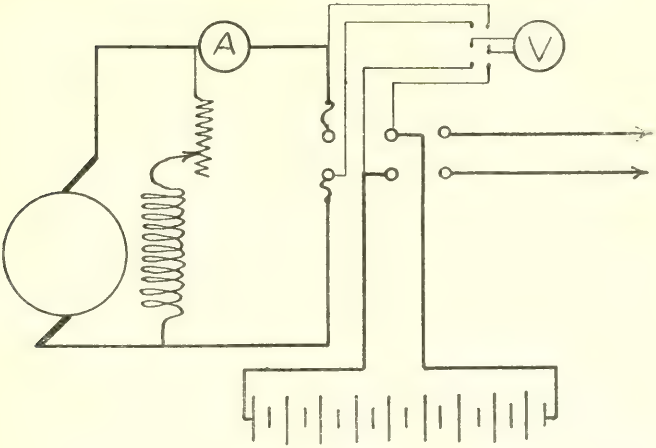


Fig. 4.

A somewhat larger plant with more refinements than the one just considered and some added advantages will now be considered. This plant can be started from the switchboard, without the necessity of "cranking" the engine, by using the battery to operate the dynamo as a motor. The motor turns the engine and with the ignition switch closed an explosion results after a few revolutions. By the use of counter E. M. F. cells, it is possible to charge the battery while power is being used for lighting or to use the combined capacity of the battery and generator to operate a large motor for a short time. Thus it is possible to obtain full 24 hour service and also to carry large loads for a short time if it is desired. The initial cost of the installation is about as follows:

Switchboard	$120.00
Engine, 2 horsepower	150.00
Generator, 1 kilowatt	100.00
Battery	290.00
Belt, foundation, piping, etc	25.00
House and barn wiring	75.00
	$760.00

The battery has the following capacity:

Hours	No. of 16 C. P. Tungsten lamps	No. of 16 C. P. carbon filament lamps	Watts
3	45	16	900
4	37	13	750
6	27	10	550
8	22	8	450
10	19	7	380

If the combined capacity of the battery and generator is used, the output is increased 1000 watts, which is enough to supply 50 16-C. P. tungsten lamps or 18 16-C. P. carbon filament lamps. A two horsepower motor can be used three or four hours before the battery is exhausted, after which all the power will have to come from the generator, and the plant can then supply only about a 1-horsepower motor. It is very evident from this that there is no economy in using the isolated plant for motor service. Driving the generator requires a two-horsepower engine which can just as well be of the portable type so that it can be used for other farm work when not required to charge the battery. This makes the full two-horsepower of the engine available for power instead of only one-half of this amount which the electric motor will deliver.

The annual expenses of the plant just described are:

Interest, $760.00 at 6%..............................	$ 45.60
Depreciation of engine and battery, $440 at 10%...	44.00
Depreciation of other equipment, $320 at 5%........	16.00
Taxes and repairs, $760 at 2%......................	13.20
Lamp renewals	10.00
Gasoline, oil and supplies..........................	40.00
	$168.80

Summary—Isolated Plants.—The cost of supplying electric power by an isolated plant is low when only the actual costs of production, or manufacturing costs, are considered, and the interest on the investment, and depreciation of the machines are neglected. This is what most advertisements and catalogues do whenever they show a low cost for lighting country homes by this method.

As a summary we may state that the isolated electric plant is satisfactory from the standpoint of convenience, reliability, safety, low operating expenses and general utility. However the first cost is high and this makes the yearly charge, or fixed cost, higher than that of either gasoline or acetylene lighting outfits. Electric lighting has many advantages over gas lighting, which makes it unfair to figure the relative merits of different systems from economic standpoints only. The added advantages of electric lights somewhat compensate for the higher first cost of the plant, so that the service and merits of all systems should be carefully weighted and balanced against their respective costs.

In all cases where the best system is wanted regardless of cost, the isolated electric light plant is most satisfactory. In many other cases we believe that it will be chosen, not because of its cheapness, but because of its many advantages.

RURAL DISTRIBUTION OF ELECTRIC POWER.

An earlier part of this bulletin shows the advantages and economy of using electric power in rural districts and also that its use has increased in the past few years; a large increase in the next decade is predicted. Inasmuch as isolated plants are unsatisfactory for power purposes and usually are not economical for lighting purposes, means of obtaining electrical energy on farms must often be obtained elsewhere.

The author of this bulletin believes that the solution of the problem of obtaining electric power on the farm lies in the purchase of energy from a central electric station. The only disadvantage of this is the fact that a long transmission line is needed to serve only a few customers. The farmers can either co-operate to build this line past their several homes and connect with a nearby city plant, or preferably they can influence the central station to build the line by a promise of sufficient business to make the enterprise profitable for the station. In the first case, the energy would be purchased and measured at the city limits. The price per unit of energy would be very low as the character of the load makes it desirable for the central station to serve this class of customers. The farmers corporation would pay for line losses, transformer losses, line repairs and all superintendence. They would also pay fixed charges on the investment such as taxes, interest and depreciation, so that the cost of power at their several homes would be considerably higher than at the city plant. If the central station were to build the line, they would have to receive all the above items as well as a fair profit on the investment from the farmers in their monthly bills, but as the larger company could probably install and maintain the system more economically, the cost of power to the farmer would be about the same as if they owned the distribution system. As the yearly cost of energy is about the same in either case, it is of course preferable for the farmers to induce the central station to build the line so that the initial investment will be a minimum.

Rural Distribution from Viewpoint of Power Plants.—From the viewpoint of the central station we may say that rural lines have proven profitable to many central stations in the Mississippi valley. The load is well distributed throughout the day, motors being used during "off peak" periods. The lighting peak, which is usually small, does not exactly coincide with the city lighting peak due to the differences in the habits of the two classes of customers. Because of the fact that rural lines help to increase the load factor, the business is very desirable, while the cost of developing the power will in general be little more than operating expenses as no additional plant equipment is needed. Some companies require the customer to pay part of the cost of the pole line, but this joint ownership of property by customers and utility corporations may lead to future difficulties. The company may require an advance payment equal to all or part of the cost of line construction, this money to be applied on future power bills. The company may require that each farmer build his own branch line from the main distribution line, and furnish his own transformer and meter, or pay rental on the same to the central station. In general, the more the customer furnishes, the lower the unit cost of power must be, while if the equipment paid for by the farmer is excessively large few customers will be secured. If the power plant furnishes everything, the price of power per unit may be so high that there will be difficulty in securing many customers. These two factors must be balanced to suit local conditions.

The first year's business may not, and probably will not, show any profit, but after the advantages are once seen by the farmers a fair income is the natural result. This has been the experience of several small central stations in neighboring states, and also of the large western plants which supply power for irrigation. The entire matter hinges on whether enough power can be sold to take care of the high investment charges. Each power plant operator must judge for himself what his market conditions will be. Later in this paper there are given some examples of typical lines under different load conditions, with costs completely analyzed. From these, some idea of the feasibility of rural distribution can be obtained after the market conditions have been studied.

General Scheme.—Regardless of whether the distribution system is paid for by the farmers, by the station or by both, the general design and construction will be the same. If the line passes through the city, it is necessary to transmit the power to the outskirts of the city at the regular city distributing voltage, which in most cases for small cities is 2200 volts. A special line may be built from the plant or the city mains may be used if they have sufficient capacity to give good regulation on the long rural lines. It is best to use a separate line from the power house, as complete control of the long system is then afforded at the station switchboard, and any trouble on the rural line, which is very susceptible to interference, will not affect the city customers. The disadvantage of this plan lies in its increased cost.

Voltage.—In the case of many systems, distribution may be effected at 2200 volts while in some cases where the load is large, or the distance great, 6600 volts must be used. In the latter case, an outdoor pole type transformer with a simple outdoor oil switch, and high tension fuses must be installed at the city limits, unless permission can be secured to run a 6600 volt line through the city streets, in which case the transformer and protective apparatus may be installed in the plant. It is not desirable to use a higher voltage than 6600 for direct distribution, as transformers are not made in the very small capacities for higher voltages. As each customer must have a separate transformer at his home, many small transformers will be required. If it becomes advisable to use a higher voltage than 6600, it is preferable to make two transformations. Thus the main transmission line voltage will perhaps be 16500. Branch circuits will be extended to several customers at 2200 volts and again transformed to 110 or 220 volts at the farmers' homes. This makes a complicated system, but one that has proven satisfactory to a few central stations which transmit power from their main plant to small towns near by and supply power to farmers located along their transmission lines.

Three Phase vs. Single Phase Systems.—The fact that rural distribution of electrical power can be effected economically and profitably is generally conceded, provided farmers can be induced to make use of motors for the many operations in which power can be advantageously applied, and if no unusual features are necessary in the distribution system.

From the farmer's standpoint, a three phase system is preferable. A single phase motor and one transformer costs more than a three phase motor and a bank of transformers for three phase use. The three phase motor is best adapted to farm use because it is simpler, more rugged and has electrical and mechanical characteristics which make it more suitable to the farmer's particular use.

As the central station's profit depends to a great extent upon the amount of the motor load, and as a large motor load can be best secured by extending satisfactory service at a reasonable cost, it seems highly advisable to gain the good will of the customers by giving them the advantages of the use of three phase motors. Since it is always advisable, and in many cases essential, to secure a large motor load, it follows naturally that a three phase transmission line should be used under all except extreme conditions.

If a small motor load, and a large lighting load can be secured at the time of installation, it may be wise to erect a single phase system at first which will later be changed to three phase when there is a possibility of increasing the motor load. The saving of copper and insulators made by using the one phase instead of the three phase system will be about $60 per mile for very lightly loaded lines, where sufficiently good regulation can be secured with a single phase line using No. 8 or No. 10 copper wire and 2200 volts. In case a large wire or a higher voltage must be used to secure good regulation with a single phase system, it is economical to change to a three phase system. If the cost of power lost is a deciding factor in selecting the size of conductor, then three phases will be most economical, since to transmit the same amount of power with the same line loss the three phase system requires only three-fourths as much copper as the single phase system.

It is thus seen that a three phase system is the most economical to use in all except very lightly loaded lines. As it is very doubtful if lightly loaded rural lines could be profitably installed, it appears that in all cases where a rural line is feasible, three phase systems should be used.

Besides the three wire three phase system, there is another which might be profitably used, namely the three phase four wire system. The primaries of the transformers are delta connected to the 2200 volts 3 phase circuit, while the secondaries are arranged in star and the fourth wire connected to the neutral, which is usually grounded. This gives with three 2200 volt primary 2200 volt secondary transformers a voltage of 2200 volts from any wire to the neutral, or to ground, with 3800 volts between any two outside wires. The copper economy and regulation are almost as good as in a 3800 volt 3 wire 3 phase system, while the voltage strains to ground which have to be met are only those of a 2200 volt circuit. Since the size of the conductors vary inversely as the square of the voltage a large saving in line material can sometimes be made by using this system.

Design of Distribution System.—In the design of a rural distribution system, the engineer is confronted by several economic problems which are different from those encountered in either a city distribution system or in a long distance power transmission line. The load will in general be small and widely distributed and will be subject to large fluctuations. The lighting load will, of course, obey the same general laws that apply in any distribution system, but motors will be used at infrequent intervals, and consequently high peaks may occur at unexpected times, while the average load will be low. These peaks will not affect the station as they will generally occur at times when the plant is lightly loaded. Also they will be far below the capacity of the plant, but they may tax the ability of the distribution system to deliver power with good regulation.

As the average load is small and as absolute continuity of service is not essential a construction of a light character is permitted and even necessary if the central station is to realize a profit. The fixed charges on the cost of the conductors will usually exceed the cost of the line loss. Therefore the smallest conductors that will give good regulation should be used. To keep down investment charges, the first pole line should be constructed as cheaply as is compatible with safety. An interruption in the service of a few hours, while being undesirable is permissible, as farmers do not need absolute continuity of service so much as service itself. The line need not be made more expensive to secure uninterrupted service although in some instances repairs could be greatly reduced by a little better initial installation.

In the long run a cheaply constructed line would probably be more expensive than one of better construction on account of its high maintenance costs. In constructing a line into new territory there is some uncertainty as to the revenue which may be derived, and a possibility that the project may be abandoned entirely after a few years trial. A line of low first cost will minimize the financial loss in such an event.

Once the business is established, however, the line must be regarded as a permanent installation and all permanent installations should be designed to secure the lowest total annual cost, including depreciation and maintenance charges as well as the interest on the initial investment.

Poles.—In general the pole line should resemble that now used for rural telephone lines. A twenty-five or thirty foot wooden pole should be used as it is sufficiently long and much cheaper than longer ones. If twenty-five foot poles set five feet in the ground are used the lowest part of the span will be at least 15 feet from the ground. This is sufficient for any place except road or railroad crossings. At road crossings thirty or thirty-five foot poles should be used and at railroad crossings the poles should be larger and set close to the right of way on each side. Many different kinds of wood are used for poles, such as cedar, pine, chestnut, cypress, redwood, fir, spruce and juniper, but the engineer can easily be guided in his choice by considering the cost. The cheapest pole should be selected for the initial installation, but for later lines, after the system has become a profitable enterprise a pole should be selected for which maintenance and depreciation charges are a minimum. This selection is made by dividing the first cost of the pole by the number of years of life and adding the yearly cost of repair and attendance, such as painting or resetting.

The life of poles, according to various authorities, is given in Table 4.

TABLE 4.

Material	Life in years
Cedar	12 to 20
Pine	6 to 10
Redwood	15 to 20
Fir	15 to 20
Chestnut	12 to 15
Cypress	9 to 10
Juniper	8½
Steel	25
Structural Iron	25
Concrete	Indefinite except for mechanical injury

It has been proven beyond any possibility of doubt that a pole which has been treated with the proper preservative has a much longer life than an untreated pole of the same material. The usual preservative is creosote. This material is introduced into the pores of the wood by several different methods, which may be divided into three general classes, namely: vacuum process, open tank process and painting. The vacuum process requires expensive apparatus and is utilized only by companies using a large number of poles. Poles treated by this method however can be purchased from some companies. The other two methods are directly appliable for use by small companies and farmers. In the open tank process, the butts of the poles are placed in heated preserving materials contained in an open tank of proper size. The cost of treating poles in this manner is low and very good results are obtained. In many cases painting the poles with the proper preservative will greatly lengthen their useful life. It is claimed by some engineers that these two cheaper processes are just as good if not better than the more expensive vacuum process. We are not in a position either to prove or to disprove this statement. Line poles usually decay first at about the level of the ground and this part of the pole at least should be painted since the cost is low and much useful life is added to the pole. Whether the pole should be treated more than this depends entirely upon the cost and the added life. If the added life will more than pay for the treating, then the poles should be treated if possible.

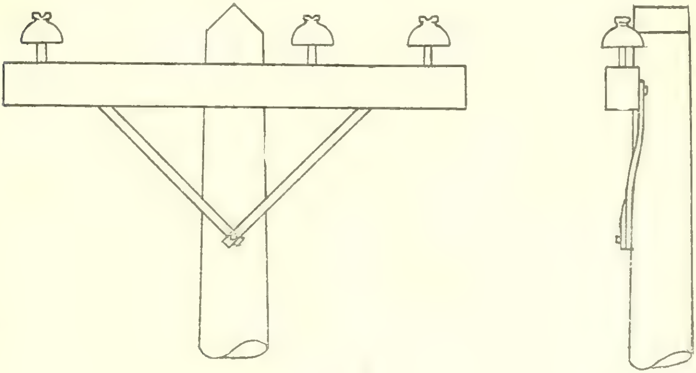


Fig. 5.

Cross Arms.—Cross arms as well as poles are made from several different woods and the same general rules apply in their selection. They need not be treated, but should be rounded on top and well painted. Their life is usually less than that of the pole because they are sawed from large logs and so the grain is exposed to the elements. To secure the cross arm to the pole, a gain is cut in the pole into which the arm is fitted and a bolt is passed through both; or lag screws may be used passing through the arm into the pole. Sometimes iron braces are added to make the cross arm more secure in its position. Cross arms, braces and pins for insulators should be placed in position on the poles before erection. Figure 5 shows pole top construction.

Cross arms on two adjacent poles face in opposite directions.

Insulators.—Insulators are usually made of glass or porcelain, pin type insulators always being used for low voltages. Glass insulators are very much used on low voltage distribution systems for both the secondary and the high tension lines while porcelain is used on all very high tension systems. Glass is cheaper but it is not as strong, or as good an insulator as porcelain. For 2200 volt systems glass insulators will probably be used because of their cheapness. For 6600 or 13200 volts glass or porcelain may be used while for voltages above this porcelain should be used. The difference in cost of line using different kinds of insulators will not be great since all low voltage insulators are comparatively cheap.

The insulators are secured to the cross arms or poles by wooden pins, steel pins, or wooden brackets. On rural lines wooden pins are best for use on cross arms.

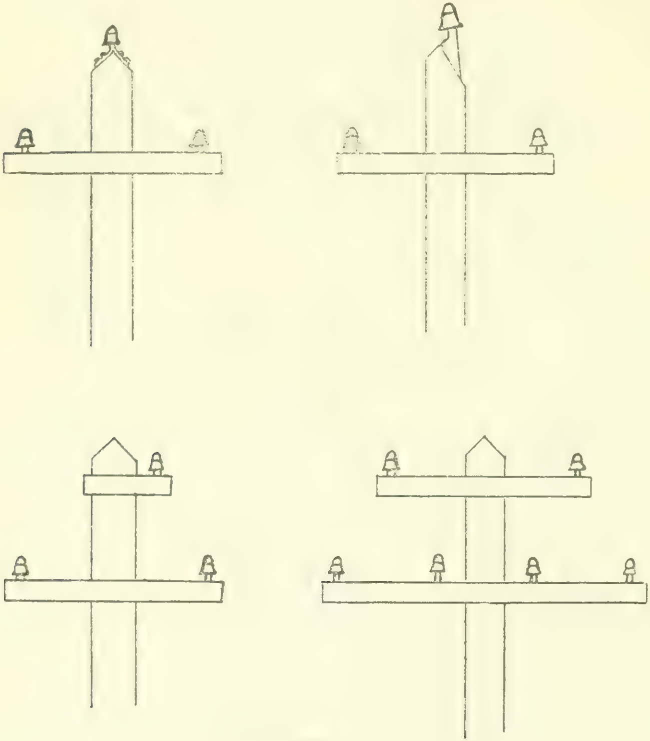


Fig. 6.

Arrangement of Conductors.—A single phase system requires but two wires and two insulators per pole which should be placed on the ends of a short cross arm placed near the top of the pole. This arrangement is the same as is shown in figure 5 except that the center insulator is to be omitted.

A three phase system requires three wires and three insulators per pole which may be placed in the form of an equilated triangle or all in one plane as shown in figure 5. The triangular construction is best, several forms of which are shown in figure 6.

If the three conductors are secured in one plane on a long cross arm they should be transposed every mile to keep the voltage the same on all three phases.

If there are telephone lines near the distribution system, the wires should be transposed frequently even with the equilateral triangular arrangement.

Line Conductor Calculations.—The selection of the proper size of conductor, and the proper voltage is a complex and rather difficult problem. There are three factors which must be considered: mechanical strength, voltage regulation and total annual cost. The regulation must be sufficiently good for the service. The cost of supplying all distribution losses, plus the fixed charges on the installation should be a minimum. For some new installations the line losses may be greatly increased to reduce the first cost thus making the sum more than the minimum. But either mechanical strength or voltage regulation is usually the controlling factor in determining the size of conductors, the line losses being a secondary consideration since the cost of supplying them is usually far less than the fixed charges on the equipment.

Assuming sufficiently close regulation for the service expected, we shall proceed on the basis of securing the cheapest installation. The line which is at first selected may be somewhat modified later to reduce distribution losses. There are several factors which affect the regulation of an alternating current distribution system such as size of conductors, kind of system (one phase or three phase), voltage, spacing of conductors, load and power factor. The costs which are varied by changing either the size of conductor or the voltage are: the cost of conductors, insulators, protective devices, switches and transformers. A change in the voltage or size of conductor also affects the line copper loss, the transformer copper loss and the transformer iron loss.

Of these several factors, some can be eliminated by inspection. The load and power factor are fixed by the customers. The use of single phase or three phase system is determined by several factors.

as discussed on page 21; a three phase system should be used in most cases. The spacing of conductors is determined by the liability of accidental contact. We thus have left only the size of conductors and voltage to be considered in the design of the system.

To secure a given regulation, we may use a small wire and high voltage or a large wire and low voltage. In the former case, the line copper cost is small and the cost of transformers, insulators, switches and protective devices is high. The transformer iron loss is also high. In the latter case these relations are reversed. It is evident that there is a certain size wire and voltage which will give a minimum cost for all the elements concerned.

The most satisfactory method of determining the proper size of the conductors and the proper voltage is by trial. First assume that No. 8 or No. 10 wire is to be used, depending upon the mechanical strength necessary. Then find the standard voltage which will give sufficiently good regulation and compute the costs of all variable elements. Next consider the next lower standard voltage and select the proper conductor for the required regulation, again computing the cost of all variable elements. The distribution losses and the cost of supplying them are also calculated for both installations. After all these are tabulated the proper selection may be made.

The following formulae have been found to be valuable. For a certain conductor (No. 8 or No. 10) the voltage which gives the required regulation is

$$\mathbf{E} = \mathbf{a\,b\,c}\sqrt{\mathbf{D\,P}}$$

Where $\mathbf{E}$ = Voltage between conductors

$\mathbf{D}$ = Distance in thousand feet to the center of distribution

$\mathbf{P}$ = Total K. V. A. which may be connected to line at one time

a, b and **c** are constants

"**a**" takes into account the kind of system. For

1 phase, $\mathbf{a} = \sqrt{2} = 1.414$

3 phase, $\mathbf{a} = 1$

2 phase, 3 wire, $\mathbf{a} = 1$ (common conductor must be larger than outside conductors)

2 phase, 4 wire, $\mathbf{a} = 1$

3 phase, 4 wire, $\mathbf{a} = 1$ (where E = voltage between two outside wires)

$$b = \left(\frac{\text{Reg}}{1000\ \text{R}}\right)^{1/2}$$

Where **R** = resistance of 1000 ft. of conductor as given in the table below.

Reg = required regulation expressed as a decimal (thus: 3% regulation = .03)

b for different size conductors and different regulations is plotted in the curves on page 30.

c is a constant which takes into account the reactance of the line and the power factor of the load. In other words it is a constant to change the regulation which would be obtained in a direct current system to the regulation which is obtained with an alternating current system. For 100% power factor **c** is always unity and for most rural lines at any expected power factor is sufficiently accurate if assumed equal to unity. The exact value of **c** is found from the curve on page 32 as explained later.

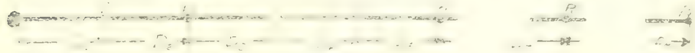
D = distance in 1000 of feet to the center of distribution of the system

$$D = [(P_1+P_2+P_3+P_4+\dots+P_n)D_1 + (P_2+P_3+P_4+\dots+P_n)D_2 + (P_3+P_4+\dots P_L)D_3 + (P_4+\dots+P_L)D_4 + \dots + (P_m+\dots+P_n)D_m + P_nD_n] \div [P_1+P_2+P_3+P_4+\dots+P_n]$$

Where P_1, P_2, P_3, P_4, ... P_m, ... P_n are the connected loads of individual customers in KVA, and D_1, D_2, D_3, D_4, ... D_m, ... D_n, are the distances between them in thousands of feet.

The proper size of conductors for a certain voltage and a required regulation, may be determined by the use of the following formula:

$$R = \frac{1}{a^2c^2} \cdot \frac{E^2 \, Reg}{1000 \, DP}$$



Supply end of line

Fig. 7.

The value of **R** per 1000 feet of commercial copper wire is shown below:

Size wire B & S Gauge	10	8	6	4	2	0	00	000	0000
R	.9972	.6271	.3944	.248	.156	.09811	.0778	.0617	.04893

To find **c** from the curve on page 32 proceed as follows: Draw a vertical line through the points which correspond to the spacing of the wires, and at the point where this line intercepts the curve corresponding to the size of the wire used, draw a horizontal line until it intercepts the curve corresponding to the power factor of the system. From this intersection draw a vertical line to the top of the figure and read the value of "c" from the scale. This gives

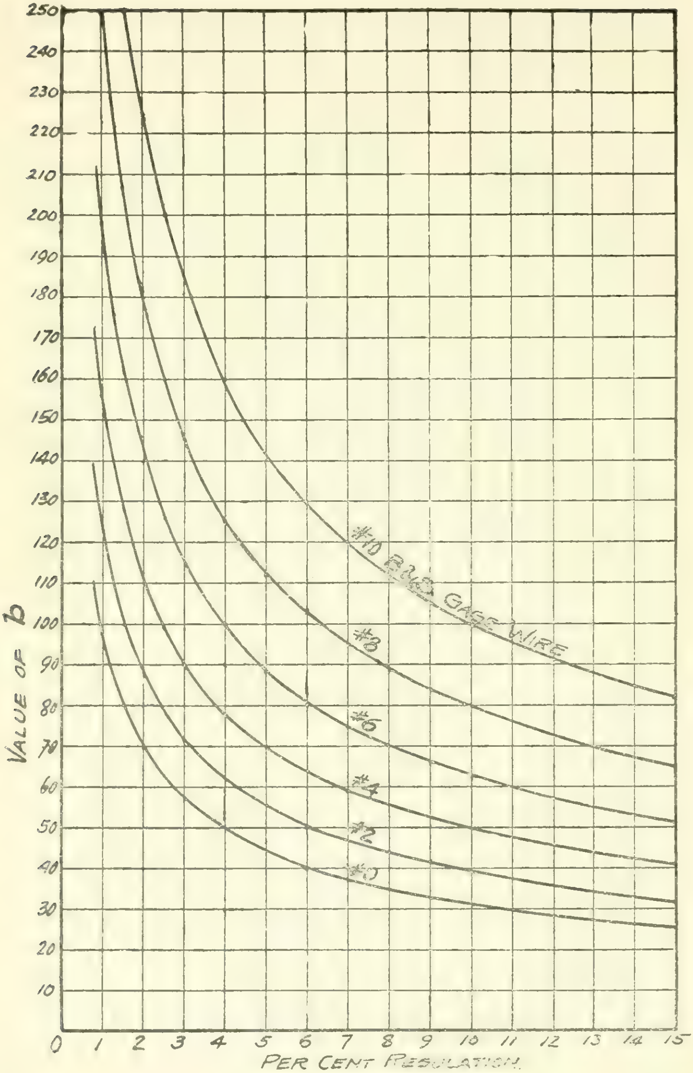

250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
VALUE OF b
PER CENT REGULATION
#10 B.&S. GAGE WIRE
#8
#6
#4
#2
#0

Fig. 8.

the proper value of **c** to use. As an example: find the value of **c** for a system using No. 6 wire spaced three feet apart and having 80% power factor. The vertical line through the three foot point is the heavy line about the center of the page. This intersects the No. 6 curve at a ratio factor of .37. Through this point draw a horizontal line which intersects the 80% power factor curve at a value of **c** equal to 1.03 which is the proper value for these conditions.

A Special Distribution System.—As an example of the design of a distribution system for rural communities let the following problem be assumed: A city plant has a three phase 2200 volt generating equipment of ample capacity to supply the load for a line as given in the following table. The manufacturing cost of power is one cent per kilowatt hour. At the switchboard the selling price of power for off peak service is one and one-half cents per kilowatt hour and the selling price of power for peak service is six cents per kilowatt hour. The customers and the individual connected loads are as follows:

Customer	Distance from city in 1000 feet.	Connected Light load in K. W.	Connected Motor load in H. P.	Required Transformers		Remarks
				No.	K.V.A. rating each.	
A	1	1	0	1	1	
B	2	½	0	1	½	
C	3	½	3	2	2	Motor used 20 hrs. per day 3 months per year to irrigate truck farm
D	5	1	0	1	1	
E	5	1	5	2	3	General service motor
F	5	½	0	1	½	
G	6	½	0	1	½	
H	8	1	10	2	7½	General service motor
I	10	½	0	1	½	
J	11	1	3	2	2	General service motor
K	11	½	0	1	½	
L	13	1	2	2	2	Motor used 10 hrs. per day throughout yr. for pumping water
M	14	½	0	1	½	
N	16	½	10	2	7½	General service motor
		10	33			

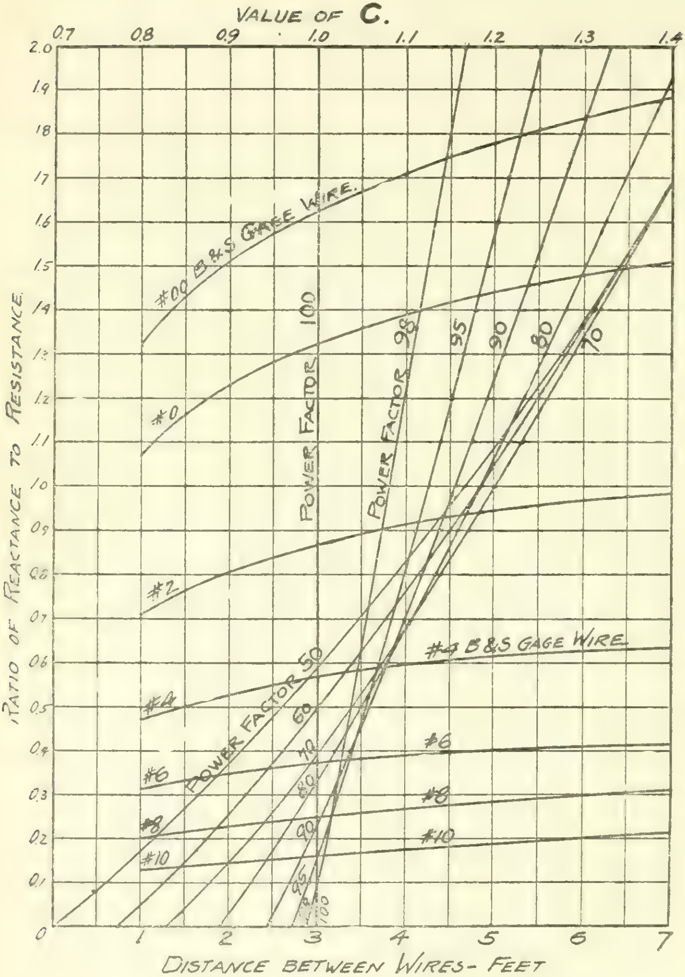

VALUE OF C.
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RATIO OF REACTANCE TO RESISTANCE
#00 B&S GAGE WIRE.
#0
#2
#4
#4 B&S GAGE WIRE.
#6
#6
#8
#8
#10
#10
POWER FACTOR 100
POWER FACTOR 98
95
90
80
70
POWER FACTOR 50
60
70
80
90
95
98
100
1
2
3
4
5
6
7
DISTANCE BETWEEN WIRES - FEET

Fig. 9.

D for motor service is calculated as follows:

$P_1 = 3,\quad D_1 = 3 \qquad (P_1 + \ldots\ldots + P_5)D_1 = 33 \text{ x } 3 = 99$
$P_2 = 5,\quad D_2 = 2 \qquad (P_2 + \ldots\ldots + P_6)D_2 = 30 \text{ x } 2 = 60$
$P_3 = 10,\quad D_3 = 3 \qquad (P_3 + \ldots\ldots + P_5)D_3 = 25 \text{ x } 3 = 75$
$P_4 = 3,\quad D_4 = 3 \qquad (P_4 + \ldots\ldots + P_6)D_4 = 15 \text{ x } 3 = 45$
$P_5 = 2,\quad D_5 = 2 \qquad (P_5 + \ldots\ldots + P_6)D_5 = 12 \text{ x } 2 = 24$
$P_6 = 10,\quad D_6 = 3 \qquad (P_6 + \ldots\ldots + P_8)D_6 = 10 \text{ x } 3 = 30$

333

$$\mathbf{D} = \frac{333}{33} = 10.09$$

D for lighting service is found as follows:

$P_1 = 1,\quad D_1 = 1 \qquad (P_1 + \ldots\ldots + P_{11})\ D_1 = 10 \text{ x } 1 = 10$
$P_2 = \frac{1}{2},\quad D_2 = 1 \qquad (P_2 + \ldots\ldots + P_{11})\ D_2 = 9 \text{ x } 1 = 9$
$P_3 = \frac{1}{2},\quad D_3 = 1 \qquad (P_3 + \ldots\ldots + P_{11})\ D_3 = 8\frac{1}{2} \text{ x } 1 = 8.5$
$P_4 = 2\frac{1}{2},\quad D_4 = 2 \qquad (P_4 + \ldots\ldots + P_{11})\ D_4 = 8 \text{ x } 2 = 16.$
$P_5 = \frac{1}{2},\quad D_5 = 1 \qquad (P_5 + \ldots\ldots + P_{11})\ D_5 = 5\frac{1}{2} \text{ x } 1 = 5.5$
$P_6 = 1,\quad D_6 = 2 \qquad (P_6 + \ldots\ldots + P_{11})\ D_6 = 5 \text{ x } 2 = 10.$
$P_7 = \frac{1}{2},\quad D_7 = 2 \qquad (P_7 + \ldots\ldots + P_{11})\ D_7 = 4 \text{ x } 2 = 8.$
$P_8 = 1\frac{1}{2},\quad D_8 = 1 \qquad (P_8 + \ldots\ldots + P_{11})\ D_8 = 3\frac{1}{2} \text{ x } 1 = 3.5$
$P_9 = 1,\quad D_9 = 2 \qquad (P_9 + \ldots\ldots + P_{11})\ D_9 = 2 \text{ x } 2 = 4.$
$P_{10} = \frac{1}{2},\quad D_{10} = 1 \qquad (P_{10} + \ldots\ldots + P_{11})\ D_{10} = 1 \text{ x } 1 = 1.$
$P_{11} = \frac{1}{2},\quad D_{11} = 2 \qquad (P_{11}) \qquad D_{11} = \frac{1}{2} \text{ x } 2 = 1.$

76.5

$$\mathbf{D} = \frac{76.5}{10} = 7.65$$

From an examination of the load conditions it is evident that the motor load which may occur at one time is 5 H. P. plus a part of the 28 H. P. in general motors. Let it be assumed that one-half of the general service motors may at some time be connected.

$$\text{Then } \mathbf{P} = 5 + \frac{28}{2} = 19 \text{ H. P.}$$

1 H. P. in an induction motor requires about 1 KVA.

Then $\mathbf{P} = 19\text{KVA}$

For induction motor service 10% regulation is sufficiently good. The values found above may now be substituted in equation (1).

$$\mathbf{E} = \mathrm{abc}\sqrt{\mathrm{DP}}$$

$\mathbf{a} = 1$ for 3 phase system
$\mathbf{b} = 79$ for No. 8 wire and 10% Reg. from the curve on page 30.

c = .98 for a system using No. 8 wire spaced 28″ and with 80% power factor, from curve, page 32. This gives

$$E = 1 \times 79 \times .98 \sqrt{10.09 \times 19} = 1074 \text{ volts.}$$

As 2200 volts is the next higher standard voltage, and is also the voltage of the city system, No. 8 wire and 2200 volts may be considered as being suitable for the motor service.

For lighting service the voltage is found as follows:

$a = 1$

$b = 145$ for No. 8 wire and 3% regulation from the curve on page 30.

$c = 1.01$ for 98% power factor and No. 8 wire spaced 28″.

$$E = 1 \times 145 \times 1.01 \sqrt{7.65 \times 5} = 906 \text{ volts.}$$

and

It has been assumed in the above that one-half of the total connected lighting load will be supplied at one time. Therefore if the line is constructed of No. 8 wire spaced 28″ and the power is distributed at 2200 volts, the proper regulation will be given. This regulation has been assumed to be 10% for induction motor service, and 3% for lighting service. The motor and lighting load will not occur at the same time so that we are safe in designing the system for the one load which presents the severest conditions. There is no need to consider any other voltage than 2200 since the cost can not be lessened by changing any of the factors. However, it may be interesting to consider the financial condiitons and the economic feasibility of a distribution system such as this one which is fairly typical of a small line after a few years operation.

Assuming that the customer purchases his own transformer and meter and also builds his own branch line from the main distribution system, the initial cost of this system is composed of the folfolwing items:

2390 lbs. No. 8 bare hard copper wire at $20 per 100 lbs......	$478.00
120 25-ft. poles, 40 per mile, at $3.50 each..................	420.00
120 3-ft. cross arms, at $0.25 each..........................	30.00
360 2200 volt insulators, at $0.04 each.......................	14.40
120 sets pole hardware, bolts, braces, pins, etc.............	18.00
Labor, setting poles, placing cross arms and insulators......	240.00
Labor, stringing wires	75.00
Incidentals	75.00
Switches, fuses and lightning arresters....................	149.60
3 mile line complete costs..........................	$1500.00

This distribution system can be cheapened by using ¼″ galvanized steel strand in place of No. 8 copper wire the regulation still being better than the standards which have been set, but the future capacity will not be quite so large. The system as now designed will take care of several times the present assumed load and with ¼″ galvanized steel strand about 1.3 times the present assumed load. Under these new conditions the cost will be

4800 ft. ¼″ galvanized steel strand, at $0.75 per 100 ft.	$320.00
90 30-ft. poles, 30 per mile, at $4.50 each	405.00
90 3-ft. cross arms, at $0.25 each	22.50
270 insulators, at $0.04 each	10.80
90 sets pole hardware	13.50
Labor, setting poles, placing arms and insulators	180.00
Labor, stringing wires	100.00
Incidentals	75.00
Switches, fuses and lightning arresters,	149.60
3 miles line complete costs	$1276.40

This saving is made because of the lower cost of the steel wire and because ¼″ steel strand has several times the mechanical strength of No. 8 copper wire so that we can space the poles farther apart.

The yearly cost to the central electric company will be as follows:

Fixed charges composed of 6% interest, 7% depreciation and 3% taxes and repairs, total 16% of $1276.40	$204.23
Iron loss in transformers, 4664 Kw hrs. at $0.01	46.64
Copper loss in line and of transformers, 300 Kw hrs	3.00
Supervision, attendance and clerical	100.00
Total yearly cost	$353.87

The total power sold is found as follows:

If one-third of the connected lights are used three hours per day, then 3650 Kw hrs. will be sold for lighting purposes. The use of general purpose motors is assumed as 5 hours per day for one-seventh of the motors, or each motor will be used 5 hours per week. The motor load is:

Irrigation	3 x 20 x 90	5400 hp. hrs.
Pumping	2 x 10 x 365	7300 hp. hrs.
General	$\frac{}{7}$ x 5 x 365	7300 hp. hrs.
Total		20000 hp. hrs.

And 20000 horsepower hours delivered at the motor shaft requires about 18000 kilowatt hours motor input. From the sale of this amount the central station must receive the cost of power at the switchboard, the cost of distributing it, and a profit on the cost of the distribution system. The distribution cost is $353.87, a 10% profit is $127.64, and $481.51, or 2.22 cents per Kw. hr., must be added to the price of power at the switchboard. This makes the cost of electric power to the farmer for motor use, $1.5 + 2.2 = 3.7$ cts. per Kw. hr. and for lighting purposes $6 + 2.2 = 8.2$ cts. per Kw. hr.

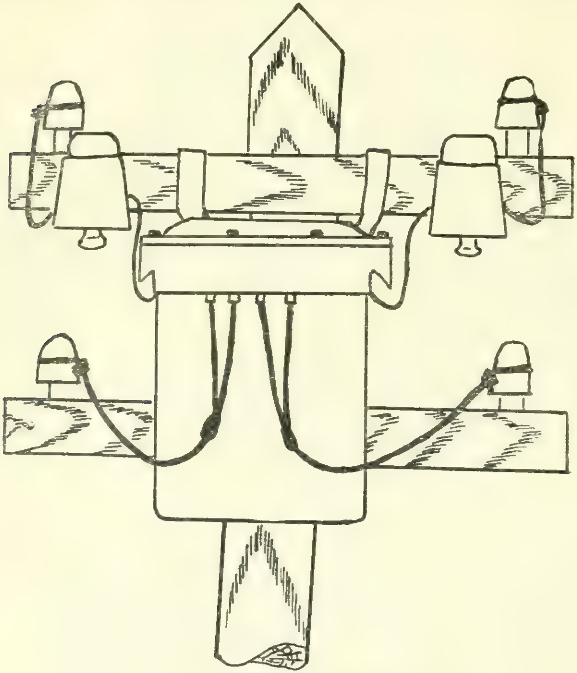


Fig. 10.—Mounting of a Transformer

Cost of Electric Service to Farmer. — It may be interesting to see what the farmer actually pays for the use of electric power. First, consider the case of a farmer who uses electricity for lighting a small residence, taking Mr. B. of the preceding problem as a fair example. He has an installation of twenty 25-watt tungsten lamps to light his six room residence. His investment is as follows for two 2-lamp fixtures and six pendant lamps, first class installation:

Wiring	$50.00
Meter	10.00
Transformer, ½ KVA	20.00
Branch line from his home to line, ¼ mile	80.00
Total	$160.00

His yearly expenses are as follows:

Fixed charges, 14% of $160.00	$22.40
Lamp renewals	3.00
Current, 180 Kw. hrs. at $0.082	14.76
Total	$40.16

His actual yearly expense will be $40.16, but he will pay the central electric company an average of only $1.20 per month.

As a typical example of the cost of motor service, consider the case of Mr. E. who has twenty-five 40-watt tungsten lamps in his residence, barn and other buildings and uses a five horsepower motor for general service. The total power used is:

Lighting, 1/3 x 3 365 = 365 Kw. hrs. at $0.082	$29.95
Motor, 4.4 x 5 x 52 = 1144 Kw. hrs. at $0.037	42.30
Total yer year	$72.25
per month	6.00

His investment is as follows:

House and barn wiring	$75.00
Meter	10.00
Two 3 KVA transformers at $35.00	70.00
Branch line, home to line, ¼ mile	80.00
Motor, 5 H. P. 3 phase, 1800 RPM	80.00
Total	$315.00

The total cost is as follows:

Fixed charges, $315.00 at 14%	$41.10
Power	72.25
Oil, waste and sundries	5.00
Lamp renewals	5.00
Total	$126.35

The cost for the lighting system is	$50.75
The cost for motor service is	75.60

Compare the above motor cost with the cost of doing the same work with a gasoline engine.

A 5 H. P. engine complete costs	$250.00
The fixed charges are, interest 6%, depreciation 10%, taxes and repairs 4%, a total of 20% on $250.00	50.00
Gasoline, 1/6 gallon per horsepower hour with 10% for leakage and waste, amounts to 238 gal., at $0.18 per gal	42.80
Oil, waste, batteries and sundries	15.00

The total for a gasoline engine is	$107.80
The total for electric motor is	75.60

The electric motor is thus much cheaper as well as safer and far more convenient and reliable.

Typical Large Rural Distribution System.—Let it be assumed that a central electric company, having a three phase 2200 volt plant, wishes to supply power for a rural line as outlined in Table 17. The company is to supply transformers and branch circuits, but each customer must purchase his own meter. The manufacturing cost of power is one cent per kilowatt hour and the profitable selling price at the switchboard is one and one-half cents per kilowatt hour for "off peak" and six cents per kilowatt hour for peak load power.

Customer	Distance in 1000 of ft.	Lighting load in K.W.	Motor load in H. P.	Remarks
A	1	1	3	Gen'l purpose motor 5 hrs. per wk.
B	1	1	5	Truck farm, used 20 hrs. per day in summer.
C	2	½	3	Gen'l purpose motor 5 hrs. per wk.
D	3	1	Two 5 H.P.	Truck farm used 20 hrs. per day in summer.
E	4	1	0	
F	6	½	Two 5 H.P.	Truck farm used 20 hrs. per day.
G	8	1	3	Gen'l purpose motor 5 hrs. per wk.
H	9	1	10	Pumping 10 hrs. per day through the year.
I	10	1	10	3 H.P. motor pumping 5 hrs.per day
			3	
J	13	½	0	
K	14	1	0	
L	16	1	5	Gen'l purpose motor 5 hrs. per wk.
M	17	2	0	
			5	5 H.P. motor general purpose 5 hrs per week
N	18	½	3	3 H.P. motor pumping 5 hrs. per dy
O	21	1	10	Gen'l purpose motor 3 hrs. per wk.
P	23	1	3	Gen'l purpose motor 5 hrs. per wk.
Q	25	1	4	Gen'l purpose motor 5 hrs. per wk.
			10	10 H.P. motor general purpose 4 hour per week.
R	26	½	3	3 H.P. motor pumping 5 hrs. per dy
S	28	1	5	Gen'l purpose motor 5 hrs. per wk.
T	29	½	0	
U	33	1	Two 10 H.P.	Power 5 hrs. per week.
V	34	1	5	General purpose motor.
W	35	½	10	Power.
X	37	15	10	Power.
Y	40	1	5	Gen'l purpose motor 5 hrs. per wk.

From an inspection of the table it is evident that the line must be designed to take care of the motor load as it presents decidedly the worst conditions. We shall therefore proceed to find **D** for the motor load.

$P_1 = 8$, $D_1 = 1$ $(P_1 \dots P_{19})D_1 = 157 \times 1 = 157$
$P_2 = 3$, $D_2 = 1$ $(P_2 \dots P_{10})D_2 = 149 \times 1 = 149$
$P_3 = 7$, $D_3 = 1$ $(P_3 \dots P_{19})D_3 = 146 \times 1 = 146$
$P_4 = 10$, $D_4 = 3$ $(P_4 \dots P_{19})D_4 = 139 \times 3 = 417$
$P_5 = 3$, $D_5 = 2$ $(P_5 \dots P_{19})D_5 = 139 \times 2 = 258$
$P_6 = 10$, $D_6 = 1$ $(P_6 \dots P_{19})D_6 = 126 \times 1 = 126$
$P_7 = 13$, $D_7 = 1$ $(P_7 \dots P_{19})D_7 = 116 \times 1 = 116$
$P_8 = 5$, $D_8 = 6$ $(P_8 \dots P_{19})D_8 = 103 \times 6 = 618$
$P_9 = 8$, $D_9 = 2$ $(P_9 \dots P_{19})D_9 = 98 \times 2 = 196$
$P_{10} = 10$, $D_{10} = 3$ $(P_{10} \dots P_{19})D_{10} = 90 \times 3 = 270$
$P_{11} = 3$, $D_{11} = 2$ $(P_{11} \dots P_{19})D_{11} = 80 \times 2 = 160$
$P_{12} = 4$, $D_{12} = 2$ $(P_{12} \dots P_{19})D_{12} = 77 \times 2 = 154$
$P_{13} = 13$, $D_{13} = 1$ $(P_{13} \dots P_{19})D_{13} = 73 \times 1 = 73$
$P_{14} = 5$, $D_{14} = 2$ $(P_{14} \dots P_{19})D_{14} = 60 \times 2 = 120$
$P_{15} = 20$, $D_{15} = 5$ $(P_{15} \dots P_{19})D_{15} = 55 \times 5 = 275$
$P_{16} = 5$, $D_{16} = 1$ $(P_{16} \dots P_{19})D_{16} = 35 \times 1 = 35$
$P_{17} = 10$, $D_{17} = 1$ $(P_{17} \dots P_{19})D_{17} = 30 \times 1 = 30$
$P_{18} = 15$, $D_{18} = 2$ $(P_{18} \dots P_{19})D_{18} = 20 \times 2 = 40$
$P_{19} = 5$, $D_{19} = 3$ $(P_{19})D_{19} = 5 \times 3 = 15$

3355

$$D = \frac{3355}{157} = 21.35$$

In estimating the value of **P** the conditions governing the use of the motors must be carefully considered. Let it be assumed that all truck farm motors are connected, that 75% of the pumping motors are connected at one time and that one-third of the general purpose motors may be connected. Near the end of the line are three power installations for rock quarries and rock crushers, and all of these may be connected at one time so that the maximum possible load is:

Truck farms		22.00 H. P.
Pumping	19 x .75 =	14.25 H. P.
General	71 x 1/3 =	23.65 H. P.
Power		45.00 H. P.
Total	**P** in H. P. =	104.9 H. P.

As one H. P. in motor capacity requires about 1 K. V. A., **P** in K. V. A. = 104.9

It is now necessary to find the voltage which is necessary to transmit this power at 80% power factor over a three phase system using No. 8 copper wire spaced 28 inches apart.

$P = 104.9$
$D = 21.35$
$a = 1$
$b = 79$ for 10% regulation curve page 30.
$c = .98$ curve page 32.
$E = abc \sqrt{DP}$
$E = 1 \times 79 \times .98 \sqrt{21.35 \times 104.9} = 3670$ volts

As 6600 volts is the next higher standard voltage it must be selected if it is desired to use a straight three phase system. A four wire, three phase, star connected system with 2300 volts between any wire and the neutral or 3980 volts between outside wires may also be used. This necessitates three transformers at each motor. The use of this latter system provides for 18% future growth while a 6600 volt three phase system allows a future load of 3.2 times the present load. As this load is hardly to be expected, 5/16″ steel strand wire may be substituted and still allow for considerable future business. A three phase, 2200 volt system requires No. 3 B. & S. copper wire and allows 15% future business. This gives three possible designs to choose from: 6600 volts three phase 5/16″ steel strand; 3980 volts three phase, four wire, with No. 8 copper wire conductors and ¼″ steel strand for the neutral; and 2200 volts three phase with No. 3 copper wire. To make a selection between these three the cost of each should be considered.

Items	Cost of a 7½ mile line		
	6600 volts 3 phase 5/16" steel strand	3980 volts No. 8 copper wire ¼" steel strand neutral	2200 volts 3 phase No. 3 copper wire
400 30′ poles spaced 100 ft., at $4.50......		$1800.00	
300 35′ poles spaced 40 per mile, at $7...	$2100.00		$2100.00
400 cross arms and set of pole hdw'r @45c		180.00	
300 cross arms and set of pole hdw'r @45c	135.00		135.00
1600 2200-volt insulators, at 4c..........		64.00	
1200 2200-volt insulators, at 4c..........			48.00
1200 6600-volt insulators, at 5c..........	60.00		
Labor setting poles	650.00	800.00	650.00
Labor stringing wires	225.00	225.00	225.00
40000′ ¼″ steel strand..................		300.00	
120000′ 5/16″ steel strand...............	1200.00		
5390 lbs. No. 8 bare copper wire.........		1079.00	
10900 lbs. No. 3 bare copper wire........			3635.00
Switches, lightning arresters and fuses..	600.00		
Total 7½ mile line....................	$4970.00	$5948.00	$7193.00
Total per mile	$663.00	$792.00	$959.00
Total Costs			
Step up transformers, 3 phase...........	$ 600	$ 560	
Distributing transformers, all single phase	3400	2300	$2300
Branch lines, averaging ⅛ mile..........	1800	2250	1800
Main line	4970	5948	7193
Total	$10770	$11058	$11293

There is very little difference in the cost of the three different systems for this installation so other than financial factors must be considered in making the selection. The third system is probably the best because it can be changed to a 3 phase 4 wire system having three times its present capacity if the future business becomes large or if it is desirable to extend the line. Futhermore, 2200 volts is the most common distribution voltage.

The total amount of power sold annually is as follows:

Lighting	6155	Kw. hrs.
Truck farms	34600	
Pumping	44500	
Power	59000	
General	16200	
	160455	Kw. hrs.

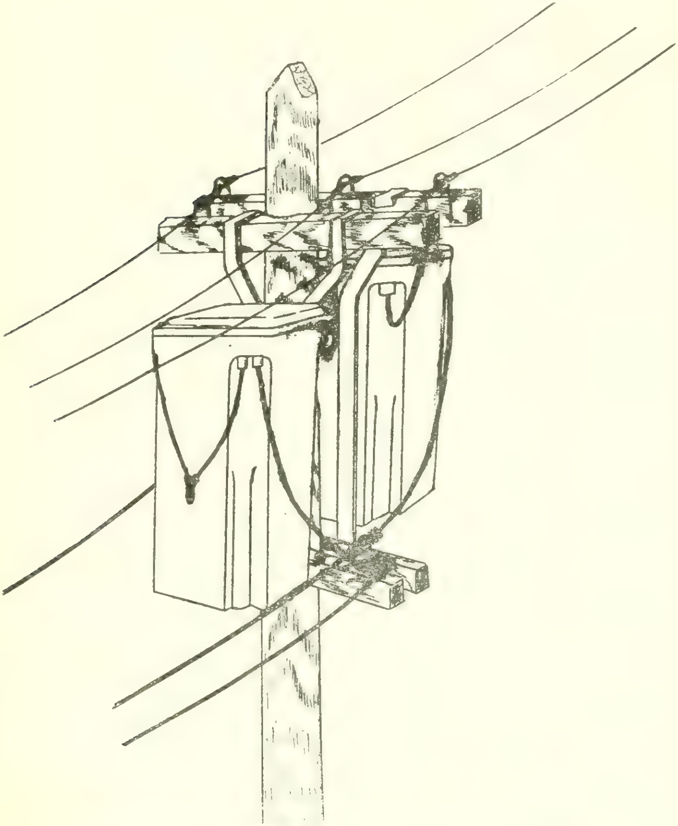


Fig. 11.—Two Transformers on a Three-Phase System.

The amount to be realized over and above selling price of power at switchboard is:

Fixed charges	$1810.00
Transformer iron loss	152.00
Copper loss	21.00
Profit 10%	1130.00
Supervision, clerical and attendance	800.00
Total	$3963.00

Additional cost per KW hr....................2.47 cents

The proper selling price of power at farmer's residence is thus:

1.5 + 2.47 = 3.97 cts. per KW. hr. for day load and
6 + 2.47 = 8.47 cts. per KW hr. for lighting service.

This selling price is higher for the heavily loaded line because the central electric station owns not only the transmission line but also the branch circuits and transformers.

Economics of Rural Distribution.—The only argument which will influence central electric stations to extend their service to rural districts must be based on income and profit. Examples of two distribution circuits have been given which show the selling price of electrical energy must be in order to make a profit on the entire investment. The first example is a short line with a medium load, built to keep down first costs. The second is a large heavily loaded rural line constructed in a first class manner, and designed for most economic operation. Neither line shows the conditions encountered on very lightly loaded rural lines.

A rural distribution system must earn a certain profit over and above all expenses including fixed charges, and this profit must be as large as can be earned by investing the same capital in other enterprises having the same degree of uncertainty. The expenses are: interest on the line investment, taxes, repairs and depreciation of the system, clerical and supervisional charges and cost of supplying all distribution losses (of which transformer iron losses are the largest) as well as the profitable selling price of electrical power at the switchboard. This price of power at the switchboard is less than the city selling price, as city distribution expenses do not have to be met. The actual profitable selling price of power at the switchboard varies through very wide limits at the different times of the day due to the varying load on the plant. At "off peak" times during the day when farm motors are mostly used, the equitable price of power may be less than one-fourth the price at the evening lighting peak time, so that a low rate for motor service is always justified if there is a high peak caused by some other load. It must not be thought that because this energy is sold at a low price there is no profit. Considering the profit on the investment required to serve the customers, motor service at a low unit price is just as profitable if not more so that the high priced lighting load.

With the exception of copper loss, which is very small, and clerical work, all the cost of distributing power over a given line is constant regardless of the amount of power which the customers use. Therefore the distributing charge per kilowatt hour varies inversely as the number of kilowatt hours sold. A line which has a heavy load usually has a better type of construction, so that this relation does not hold strictly true for two different lines.

An analysis of the cost of rural distribution shows that the following is approximately true: Copper loss is generally a negligable factor and will seldom exceed one per cent of the power sold. Transformer iron losses are usually high unless high tension disconnecting switches are provided to disconnect the transformers where they are not in use and this may be economical in some instances. For 2200 volt distribution, transformer iron losses will amount to about one per cent of the connected transformer capacity continued 24 hours per day, which amounts to 88 kilowatt hours per year per K V A in connected transformer capacity. For higher voltages, the iron losses are higher than this. Fixed charges on the investment are usually high considering the amount of power sold. A fair estimate of them is as follows:

Item	Per cent
Interest, (at current rate)..................	4-6
Depreciation of pole line (depends on type)	5-15
Depreciation of conductors.................	3-8
Taxes (at current rate)....................	
Repairs	1-5

A central station should consider nothing less than 10% profit on the investment as the business is slightly hazardous and 15% would probably be a better figure to use in preliminary computations for new lines.

To find the economical selling price of power at the farmer's homes the following formula will apply.

$$P = \frac{FC + pC + L}{\text{KW hrs. per year per mile}} + S$$

Where **P** is the selling price per kw. hr.,
F is the fixed charges in percent of total investment, assumed as 16% in our previous calculations,
p is the percent profit,
L is the cost per mile of supplying line losses.

C is the average cost per mile of all the apparatus and lines owned by the electric power company,

S is the profitable selling price of power at the switchboard varying for different service plus a small amount for clerical and supervision work.

The total amount which must be added per kilowatt hour to the economic price of power at the switch board is

1000 KW hrs. per year per mile	15.0 cents
2000 KW hrs. per year per mile	8.5 cents
4000 KW hrs. per year per mile	5.0 cents
10000 KW hrs. per year per mile	2.5 cents
20000 KW hrs. per year per mile	1.5 cents
40000 KW hrs. per year per mile	1.0 cents

This table is based on a line costing about $650 per mile, and a connected load about ten times the average load. The values given vary but little with different lengths of transmission. It is probable that the cost of lines for lightly loaded systems can be reduced below $650 per mile, so that the selling price of power for these lines can be reduced.

Distribution from High Tension Transmission Lines.—The trouble and expense of many small substations make it unwise to serve small customers from high voltage transmission lines, unless enough customers can be supplied from one transformer station to warrant the construction of a substation of the best type, with constant attendance to secure reliability of serve to the customers, and with the best protective apparatus to protect the main transmission line from disturbances originating on the customer's circuits. The income from isolated customers is seldom large enough to be profitable even after the element of risk of interruption of the main transmission service by local disturbances on the branch circuits has been subtracted. To secure full protection to the substation apparatus, a reliable and positive lightning arrester must be placed at each station; to protect the transmission system, reliable circuit breakers must be installed to interrupt the service in case of trouble. Since both of these protective devices must be designed for the transmission voltage, they are necessarily expensive. Small high voltage transformers are also costly. If uninterrupted service is to be extended to the customers, there must be constant attendance. To secure all these qualities the apparatus should preferably be enclosed in a building. All of these factors make it uneconomical and unprofitable to serve small isolated customers.

If, however, a number of customers who do not require absolute continuity of service can be connected to one substation, and

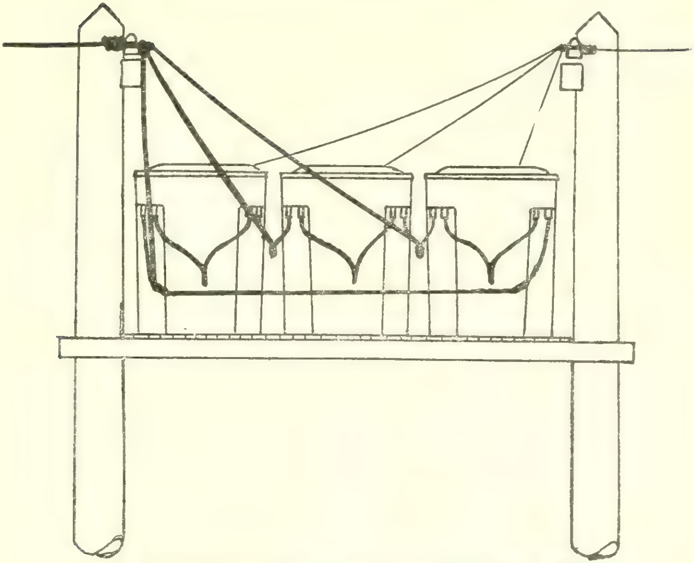


Fig. 12.—Bank of Three Transformers on a Three Phase System.

the company is willing to assume the risk of interruption of the main service, there is no reason why these customers should not be provided with electrical power. This is the case with farmers. A rural distribution system such as is described in the second problem discussed in the preceding pages could be economically and profitably served with an outdoor transformer station of 100 KVA capacity from a 33,000 or possibly a 44,000 volt transmission line. Constant attendance can be dispensed with since farmers do not require continuity of service as much as the service itself. Several companies now design outdoor transformers in small capacities for high voltages, using cheaper types of apparatus than are used for large transformer stations.

Notwithstanding the fact that the apparatus available for this service leaves something to be desired, many power companies use, and several manufacurers make sets for the protection of small outdoor transformer stations. These sets are composed of a disconnecting switch, a high tension fuse of a special design, a choke coil, and a horn gap lightning arrester. In case of a short circuit on the branch the fuse is blown. A lightning disturbance entering from the line is reflected by the choke coil to the horn gap where it discharges, the arc being broken by the natural operation of the horn gap. In case the arc is not extinguished at once, the high tension fuse which is in series with the arrester as well as the other apparatus, is blown. Thus in case of a short circuit or in some cases of lightning discharge, the circuit is opened by the fuses until they are replaced by an attendant. Whenever any work is to be done on the station, the station can be made dead by opening the disconnecting switches after the low tension switches have been opened. While this system does not secure continuity of service to the customers, and does not fully protect against transient disturbances, yet it is the best cheap installation that can be made under present conditions. A substation which would serve the customers on the farmers' line described under problem 2 would cost about $1800.

The annual expenses are:

Amount to be realized from distribution line	$3963.00
Fixed charges, 16% of $1800	288.00
Profit, 10% on $1800	180.00
Transformer iron loss	100.00
Supervision and attendance	200.00
Total	$4731.00

The amount to be added to the selling price of power to defray distribution costs is 2.94 cents per kilowatt hour, which is a very reasonable figure. Therefore, if a sufficiently good load can be connected to one substation, and if the customers do not demand absolute continuity of service, as is the case with farmers, and if the power company is willing to assume the risk of interruption of the main transmission service and to keep the transformer station in satisfactory operation, a fair revenue at a good profit is derived from serving farmers, even from a 33000 volt transmission line.

Special Central Electric Plants.—In several European countries, for example Germany, Italy and Norway, there are now in operation many small central electric plants situated in the centers of well developed farming countries. These plants have distribution systems extending to the homes of the farmers within a reasonable radius. Some of the larger plants are steam driven, many of the small ones are gasoline or oil engines, while a few utilize water power. Many of them are direct current plants using a storage battery to secure continuous service to the farmers with intermittent operation of the generator and prime mover.

While we do not know all the conditions surrounding the establishment of these plants, it appears that they are less economical than distribution from city plants or high voltage transmission lines. The satisfactory method of securing electric power on farms in America does not lie in the direction of small isolated plants. If, however, it is not possible to secure power from a large central plant, it is better and more economical for two or more farmers living near each other to use one isolated plant such as described earlier in this bulletin rather than for each farmer to have his own separate plant. The isolated plant described under problem 2 on page 17 would satisfactorily supply two small residences with light at a cost about the same as that given by supplying one residence. The cost to each farmer would be little more than one-half of the cost given previously. But this is a refinement of the isolated plant rather than a central station of the kind used in Europe.

A central plant for the use of farmers would need to be a small installation of the same type as the large city plants. There is no need of multiplying the number of small plants in a country when in general one large station can supply energy more economically than several small ones. The large plants are already installed and they will need little extra equipment to serve a large number of farmers by means of a few distribution lines. They should be used wherever possible.

CONCLUSION.

It is undisputed that farmers will find as much satisfaction in the use of electric light as any other customers. Electric motors can be profitably used almost daily in many farm processes because of their convenience, ease of operation, flexibility, lack of noise and dirt, long life, small repair charges and general overall economy. It is usually uneconomical for farmers to own and operate isolated plants since the fixed charges are high, and such plants are not well adapted to supplying motors with power. It therefore seems preferable to distribute power from a central electric plant by means of a high voltage distribution system. This is economical to the farmer and profitable to the central station if a good motor load can be secured. The best system will usually be found to be a three phase system, either three wire or four wire, with a voltage such that standard 2200 volt or 6600 volt distributing transformers can be used. The entire line should be designed for as low a first cost as is consistent with durability and general engineering practice. In the selection of the system for a particular line, the cost of all applicable systems should be considered. It is sometimes profitable for power companies to install small outdoor transformer stations to supply rural lines.

Small central stations supplying power to farmers only, and with no other market, are not likely to prove successful financially. Distribution from a city central electric station or a long distance high voltage transmission line is always to be recommended where feasible as being the most satisfactory to all concerned in obtaining electricity for lighting and power in rural districts.

THE UNIVERSITY OF MISSOURI BULLETIN

ENGINEERING EXPERIMENT STATION SERIES
VOLUME 3 NUMBER 2

COMPARATIVE TESTS OF CYLINDER OILS

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COLUMBIA, MISSOURI
June, 1913

COMPARATIVE TESTS OF CYLINDER OILS.

INTRODUCTION.

The cylinder oil tests described in the following pages are to be regarded as a continuation of Vol. 2, No. 2 of the Engineering Experiment Station Series: "Friction and Lubrication Testing Apparatus" by Mr. A. E. Flowers, formerly Assistant Professor of Electrical Engineering, University of Missouri. This bulletin was a report on the oil testing apparatus devised by him, and which has been used to test and compare the lubricating values of the samples of cylinder oils reported in the present bulletin.

It is generally agreed among operating engineers, that the present specifications based on the chemical and physical constants of an oil (the specific gravity, flash and fire tests, viscosity, acidity, per cent animal and vegetable fat, etc.), do not give sufficient information as to their value as a friction and wear reducing agent. Even these chemical and physical constants are very often not supplied to the purchaser, with the result that the operating engineer finds himself in a difficult position when he has to choose between a certain number of oils of different costs, different compositions and of different and also unknown lubricating values.

It was this difficulty experienced in the selection of a proper cylinder oil to be used at the Light and Heat Station of the University of Missouri, that has led the Engineering Experiment Station to develop an apparatus for the testing of the lubricating value of cylinder oils under conditions identical to every-day practice.

Nine samples of cylinder oils, designated by the first nine letters of our alphabet, were tested; the results of these tests are given in the following pages.

PHYSICAL PROPERTIES.

Color and Consistency. The color and consistency of the oils tested are given below:

Oil	Color	Consistency
A	Dark brown	Thick
B	Dark green	Thick
C	Dark	Thick
D	Brown	Thick
E	Dark brown	Thick

F	Brown	Thick
G	Reddish brown	Limpid, flows easily
H	Black	Thick
I	Reddish	Clear, flows easily

Specific Gravity. The specific gravity or the weight per unit volume of the oils at different temperatures was determined by using a direct reading hydrometer, and their comparative values are shown in Figure 1, where the specific gravity is plotted as a function of the temperature.

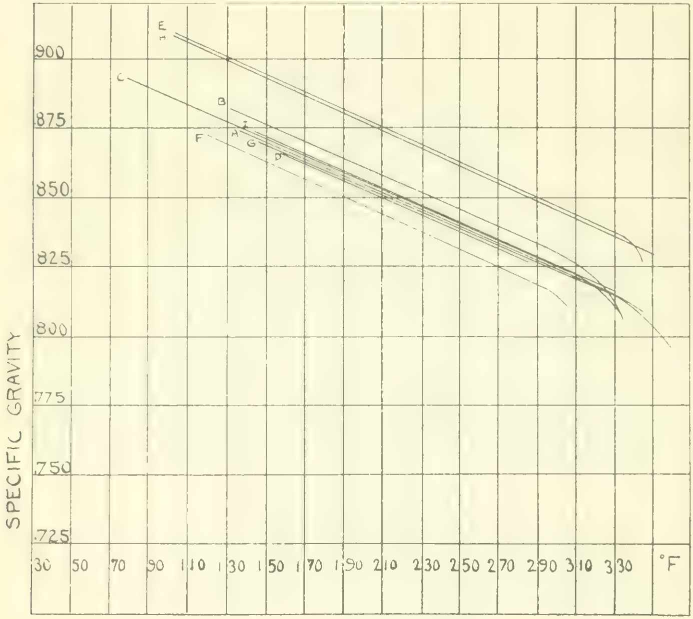

Fig. 1

From these curves we can readily see that as to their comparative heaviness at the temperature of boiling water (212°F) the oils tested rank as follows:

TABLE 1.

Oil	Sp. Gr.
E	.875
H	.873
B	.857
A	.855
I	.855
C	.855
G	.851
D	.849
F	.844

It is to be noted the oils A, C and I, though entirely different as to color and consistency have the same specific gravity throughout the range of temperatures under which they have been tested.

Flash and Fire Tests. The open flash point is the temperature at which the oil flashes under atmospheric pressure when a flame is brought near its surface. This was determined in the usual manner by nearly filling a tin cup with a sample of oil and heating it gradually over a sand bath and passing over the surface of the oil a lighted match until the oil starting to vaporize, the vapor ignites with a flash.

By repeating this test till the surface of the oil catches fire, we obtain the fire point or fire temperature.

It is generally inferred that the flash point being more or less an indication of the temperature at which an oil begins to decompose, would naturally indicate whether an oil is suitable or not for high temperature work. But it is also more or less evident that the flash and fire temperature is very much different at the various pressures in the cylinder as compared with the flash and fire temperature at atmospheric pressure because in the cylinder, the oil being, so to say, intimately mixed with steam, its chemical composition might be somewhat changed. The open flash and fire temperatures are given, as are all the other physical and chemical constants, as a possible and probable means of identifying the oils.

According to their flash points the oils ranks as follows:

TABLE 2.

Oil	Flash Temp.	Fire Temp.	Difference
D	568° F	616° F	48° F
F	568	605	37
C	559	606	47

B	553°	602°	49°
G	546°	610°	64°
A	533°	602°	69°
I	493°	564°	71°
E	487°	519°	32°
H	478°	514°	36°

It should be noted from the above table, that with the exception of oils D, C, A, I, E and H, which occupy the same rank in the flash and fire points, oil B is the fourth in the flash point and ranks the sixth in the fire test; oil F stands the second in the flash and the fourth in the fire test, while oil G is the fifth in the flash and second in the fire test. There is no apparent reason for these oils to behave in this manner.

Viscosity. The viscosity or the resistance of the oils to flow at various temperatures was measured by means of a "home made" electric viscosimeter.

This viscosimeter was made of a copper cup, fitted at its bottom with a standard nozzle, and around which was wound a resistance unit of german silver wire, the turns and layers of resistance wire being properly insulated from each other and from the cup.

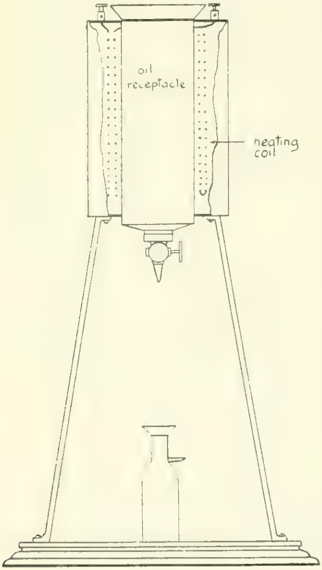

Fig. 2.

A maximum electric current of of 1.5 amperes was allowed to flow through the resistance unit, and the heat generated was sufficient to bring the oil in the cup to a temperature of 400° F in about 8 minutes. The control of temperature was obtained by varying the current in the resistance unit by means of suitable rheostat.

A sketch of this viscosimeter is shown in Figure 2.

The comparative viscosity of the oils tested are given in the following table for temperatures of 212° F, and 327.8° F (corresponding to 100 pounds steam pressure), the viscosity of water at 25° C (77° F) being taken as unity.

TABLE 3.

Oil	Viscosity At 212° F	Viscosity At 327.8° F
C	4.00	1.50
A	3.18	1.37
F	2.94	1.46
B	2.88	1.42
I	2.80	1.44
D	2.62	1.37
H	2.60	1.44
E	2.40	1.25
G	2.32	1.25

It is easily seen from the above table that at higher temperatures, the viscosity of all the oils tested approach the viscosity of water, and also that the oils do not rank in the same order for the higher temperature as they do for the temperature of 212°F.

CHEMICAL CONSTANTS OF THE OILS.

The determination of the acidity, saponification number, iodine absorption number, and per cent animal and vegetable fats were determined in the Dairy Research Laboratory by Mr. H. F. Yancey through the courtesy of Mr. L. S. Palmer, Dairy Chemist.

Acidity. The method used to determine the acidity is the one given by Allen[†], and is as follows:

Weigh about 15 grams of oil into a 200 c c. Erlenmeyer flask. Add 50 c. c. of 95 per cent alcohol which has been neutralized with a weak solution of caustic solution using phenolphthalein as indicator, and heat to boiling. Agitate the flask thoroughly in order to dissolve the free acids as completely as possible. Decant the solution through a filter, and collect the filtrate in an Erlenmeyer flask. Repeat this operation six or seven times in order to get all of the free acid into the filtrate. Titrate hot with tenth normal alkali,[‡] agitating thoroughly until the pink color persists after vigorous shaking.

The results are expressed either as percentage oleic acid or as acid value, that is, the number of milligrams of potassium hydroxide required to neutralize the free acids contained in one gram of oil tested.

It was found necessary to filter off the alcoholic solution from the insoluble oil, because the dark color of the oil obscured the endpoint of the titration.

[†] Allen, Commercial Organic Analysis, 3d Ed.

[‡] One cubic centimeter of tenth normal alkali is equal to 0.0282 grams of oleic acid.

Saponification Number. The saponification number is the number of milligrams of potassium hydroxide required to saponify one gram of oil.

The method used for its determination is the official method, as given in Bulletin No. 107 (revised) U. S. Dept. of Agriculture, and is as follows:

Preparation of reagents:

1. Alcoholic Potash Solution.—Dissolve 40 grams of chemically pure potassium hydroxide in one liter of 95 per cent redistilled alcohol. The solution must be clear and the potassium hydroxide free from carbonates.
2. Standard Acid Solution.—Prepare accurately half normal solution of hydrochloric acid.
3. Indicator.—Dissolve 1 gram of phenophthalein in 100 c.c. of 95 per cent alcohol.

Determination:

Weigh about 10 grams of oil into a 300 c. c. Erlenmeyer flask. Run in 50 c. c. of the alcoholic potash solution, put on steam bath, and connect with reflux condenser. Allow to remain on steam bath for three hours with occasional shaking. Filter through paper, and wash unsaponifiable matter with hot alcohol until one drop of the filtrate from the filter shows no alkalinity to phenophthalein. Titrate the hot filtrate against half normal hydrochloric acid using phenolphthalein as indicator.

Conduct two or three blank experiments to determine the amount of alkali added to each sample in terms of the acid. To obtain the saponification number subtract the number of cubic centimeters of hydrochloric acid to neutralize the excess alkali after saponification from the number of cubic centimeters necessary to neutralize the 50 c. c. added; multiply the result by 28.06 (the number of milligrams of potassium hydroxide equivalent to 1 c. c. half normal acid) and divide by the number of grams of oil in the sample.

The unsaponifiable matter in the oils tested had to be separated from the solution, because its presence obscured the end point of the titration.

Iodine Absorption Number. The method used for the determination of the iodine absorption number of the oils is the Hubl official method as given in Bulletin No. 107 (revised) U. S. Dept. of Agriculture.

Preparation of Reagents:

1. Hübl's Iodin Solution.—Dissolve 26 grams of pure iodin

in 500 c. c. of 95 per cent alcohol. Dissolve 30 grams of mercuric chlorid in 500 c. c. of 95 per cent alcohol. Filter the latter solution if necessary, and mix the two solutions. Let the mixed solutions stand twelve hours before using.

2. Decinormal Sodium Thiosulphate Solution.—Dissolve 24.8 gr. of chemically pure sodium thiosulphate, freshly pulverized as finely as possible and dried between filter or blotting paper, and dilute with water to 1 liter at the temperature at which the titration is to be made.

3. Starch Paste.—Boil 1 gram of starch in 200 c. c. of distilled water for 10 minutes and cool to room temperature.

4. Solution of Potassium Iodid.—Dissolve 150 grams of potassium iodid in water to make up 1 liter.

5. Decinormal Potassium Bichromate.—Dissolve 4.9083 grams of chemically pure potassium bichromate in distilled water and bring the volume up to 1 liter at the temperature at which the titrations are to be made. The bichromate solution should be checked against pure iron.

Determination:

1. Standardizing the Sodium Thiosulphate Solution.—Place 20 c. c. of the potassium bichromate solution, to which has been added 10 c. c. of the solution of potassium iodid, in a glass stoppered flask. Add to this 5 c. c. of strong hyrochloric acid. Allow the solution of sodium thiosulphate to flow slowly into the flask until the yellow color of the liquid has almost disappeared. Add a few drops of the starch paste, and with constant shaking continue to add the sodium thiosulphate solution until the blue color just disappears.

2. Weigh about one half gram of the oil on a small watch crystal; heat and mix thoroughly; pour into another watch crystal and allow to cool. Introduce the watch crystal (containing the oil) into a wide-mouth 16 ounce bottle with ground glass stopper.

3. Absorption of Iodin.—Dissolve the oil in the bottle in 10 c. c. of chloroform. After complete solution has taken place, add 40 or 50 c. c. of the iodin solution. Place the bottle in a dark place and allow to stand, with occasional shaking, for eight hours. This time must be closely adhered to in order to get good results. The excess of iodin should be at least twice as much as is absorbed.

4. Titration of the Unabsorbed Iodin.—Add 20 c. c. of the potassium iodid solution and shake thoroughly, then add 100 c. c. of distilled water to the contents of the bottle, washing down any free iodin that may be noted on the stopper. Titrate the iodin with the sodium thiosulphate solution which is added gradually, with constant shaking, until the yellow color of the solution has almost

disappeared. Add a few drops of starch paste and continue the titration until the blue color has entirely disappeared. Toward the end of the reaction, stopper the bottle and shake violently, so that any iodin remaining in solution in the chloroform may be taken up by the potassium iodid solution.

5. Standardizing the Iodin Solution by Thiosulphate Solution.—At the time of adding the iodin solution to the oil employ two bottles of the same size as those used for the operations described under paragraph 3, 4, and 5, the extra bottle being used for standardizing the iodin solution, no oil being present. The blank experiments for standardizing must be made each time the iodin solution is used. Great care must be taken that the temperature of the solution does not change during the time of the operation, as alcohol has a very high coefficient of expansion, and a slight change of temperature makes an appreciable difference in the strength of the solution.

Per cent of Animal and Vegetable Oils. According to Sherman's Organic Analysis pp. 147 and 192, if any oil has a low saponification number and also a low iodin number, it may safely be assumed that the oil in question is composed of a large percentage of mineral oil and a correspondingly small percentage of animal and vegetable fats, and if such is the case, the percent fatty oils can be estimated with sufficient accuracy for most purposes from the saponification number, since fatty oils which are likely to be present in mixed lubricants do not vary greatly in their saponification number.

In estimating the percent animal and vegetable fats present in the oils tested a saponification number of 190 was used.

The following table shows the results of the above described tests:

TABLE 4.

Oil	Free acid value	Free oleic acid	Saponif. number	Iodine number	Animal and vegetable fats
B	trace	trace	8.5	14.56	4.47
A	.133	.097	12.2	15.32	6.42
G	.125	.087	14.3	14.32	7.52
I	.575	.405	17.1	11.36	9.08
D	.238	.169	18.4	13.70	9.25
F	.098	.073	21.0	12.80	11.05
C	.176	.127	25.2	12.21	13.26
E	.367	.280	34.9	16.37	18.38
H	.362	.254	35.8	15.90	18.84

The above table shows that all oils tested have a very low acid value, also low saponifications and iodin numbers. Naturally these facts indicate the high percentage of mineral oil and the low percentage of animal and vegetable oil.*

FRICTION TESTS.

The following description of the friction testing apparatus is given by Mr. A. E. Flowers, who designed it, in Vol. 2, No. 2 of the Engineering Experiment Station Series:

"The method of measurement (of the friction coefficient) . . . was to measure electrically the input to a motor and to subtract the motor losses. The motor was provided with a crank disk and connecting rod, driving two pistons fastened on the opposite ends of a piston rod with a steam space, and a pocket for collecting condensation between pistons." . . . Two Detroit one pint lubricators "connected to steam pipes entering the cylinder near the ends, just inside the inner portions of the cylinder" fed the oil to the cylinder. "The use of two pistons with a steam space between them prevents the steam from doing any work itself or having work done on it. Each end of the connecting rod was fitted with Hess-Bright ball bearings so that its friction is negligible compared with that of the pistons." . . . . "The cylinder bore is 5 inches and each piston has 3 standard type, cast iron piston rings, the width of each being .2175 inches. These rings gave a pressure of about 3.23 pounds per inch of circumference and 14.92 pounds per square inch after being worked to a fit. As the cylinder ends are open, only one face of the piston is subjected to steam pressure and temperature, the other face being subject to conditions corresponding to those of the exhaust of a non-condensing engine."

This method of measuring the friction coefficient in a steam cylinder by means of an electric motor is not entirely new. Mr. F. C. Wagner has used it in making friction tests of a locomotive slide valve. (Proc. A. S· M. E. Vol. XXI, 1900, p. 242.)

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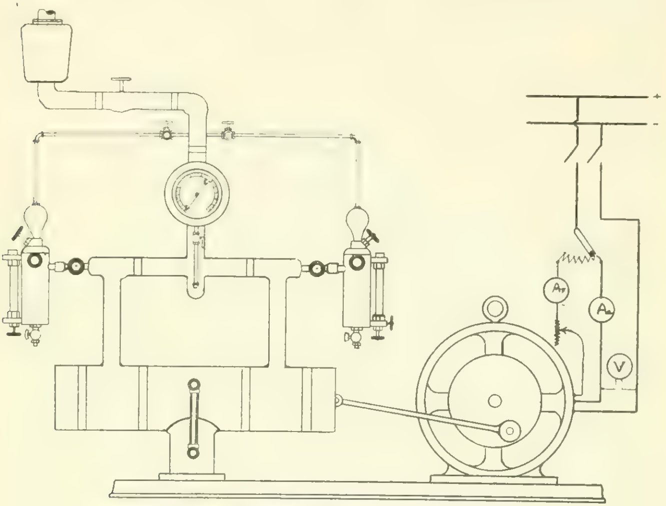
*For more detailed information on the chemical analysis of cylinder oils see A. C. Wright, The Analysis of Oils; Stillman, Engineering Chemistry; A. H. Gill, Oil Analysis; Sherman's Organic Analysis.

The following sketch shows diagramatically the testing apparatus above described.



APPARATUS FOR MAKING LUBRICATION TESTS

Fig. 3

The steam, after passing through a steam separator and reducing valve, is admitted into the cylinder, the steam pressure being obtained by means of an Ashcroft standard gauge.

The motor supplying the motive power was an Interpole motor made by the Electro-Dynamic Co. of Bayonne, N. J., and rated V. 110—H. P. ½—R. P. M. 400-1600 and throughout all the tests was run on constant supplied voltage of 90 volts and with a constant excitation of .300 amperes, the speed of the motor varying slightly from 620 revolutions per minute under various steam pressures in the cylinder, and various conditions of oil feed thus giving an approximate piston speed in the cylinder of about 520 feet per minute.

This motor has been carefully calibrated for losses by Mr. Flowers before and recalibrated by the writer after the tests were made, the difference in results being of no consequence.

Each of the oils has been tested under varying pressures up to or a little over 100 pounds per square inch steam pressure, and with three different conditions of feed, namely 10, 20 and 30 seconds to the drop, that is six, three and two drops to the minute. The feed of the oil was maintained as far as possible constant during each test.

The following readings were taken:

Voltage supplied to the motor, constant at 90 volts.

Field current of the motor, constant at .300 amperes.

Armature current of the motor, variable, depending upon kind of oil used, feed, and steam pressure.

Oil feed, in seconds to the drop.

Steam pressure in pounds to the square inch, gauge.

The temperature of the rubbing surfaces, by means of thermometers in "pockets" within 1-16 of an inch of the inner cylinder wall and opposite the mid stroke position.

Calculations.. The calculations were made as follows:

Let **E** = voltage supplied to the motor armature.
I = armature current for any reading during a test.
R resistance of the armature of motor at the working temperature.
L = friction and iron losses of the motor corrected for armature reactions occuring for an armature current (I).

Then

$$EI = \text{power supplied to the motor armature in watts.}$$

EI — (I^2R + L) = watts power output of the motor, supplied to the cylinder to overcome the friction. In terms of horse power this amounts to

$$\frac{EI - (I^2R + L)}{746} \text{ Horse Power.}$$

If **F** = drag force and
V = speed of piston in feet per minute, then

$$\text{H. P.} = \frac{F \text{ x } V}{33000}$$

Hence the drag force $$F = 33000 \frac{EI - (I^2R + L)}{746V}$$

Now if **f** = friction coefficient, and
P = normal pressure exerted on the cylinder walls,

$$f = \frac{F}{P} = 33000 \frac{EI - (I^2R + L)}{746\,V\,P}$$

Results. The results of the friction tests above described are shown graphically in the following nine plates, Figs. 4 to 12 inclusive, each plate representing the variation of the friction coefficient of one oil with the steam pressure in pounds per square inch, and also with the corresponding temperature in degrees Fahrenheit. The three curves on each plate are for three different conditions of feed, the upper curve being for a feed of 30 seconds to the drop, (or 2 drops to the minute), the middle curve for a feed of 20 seconds to the drop (or 3 drops to the minute), and the lower curve for a feed of 10 seconds to the drop (or 6 drops to the minute). Each of these curves is a composite curve of at least three different sets of observations under similar conditions of feed. For some oils as many as six different sets of observations were taken to check and thus insure uniform results.

An analysis of the curves shows that for most of the oils tested, the friction coefficient decreases with increase of the quantity of oil supplied, and also a decrease in the friction coefficient under the three different conditions of feed with increase of steam pressure, the friction coefficient becoming more or less constant with higher steam pressures.

This last statement is especially true for oils A, B, E, and G, as seen from curves Figs. 4, 5, 8 and 10.

The other oils behave in a rather peculiar manner. Thus for oil C the above statement is true only for feeds of 10 and 20 seconds to the drop, while for a feed of 30 seconds to the drop, with the exception of a slight decrease up to 50 pounds per square inch of steam pressure, the friction coefficient is almost constant at .0640.

A similar but more pronounced result was obtained for oils F and H, the coefficient of friction being .0660 and about .0510 for the two oils respectively at feeds of 30 seconds to the drop for each oil.

A still more pronounced result of a similar nature was obtained for oil D, for which the friction coefficient is constant at about .0600 and .0560 for 30 and 20 seconds to the drop respectively.

The results for oil I are still more peculiar in as much, that while the friction coefficient for a feed of 30 seconds to the drop decreases with the steam pressure as it does for the other oils at higher feeds, the friction coefficient for feeds of 10 and 20 seconds to the drop apparently increases with the steam pressure, as seen from the curves in Fig 12.

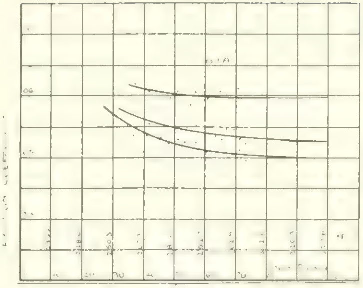


Fig. 4, Oil A.

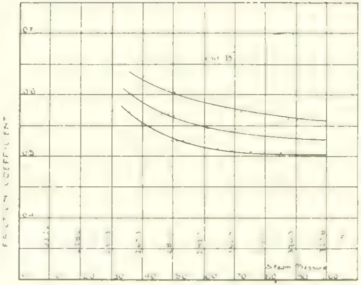


Fig. 5, Oil B.

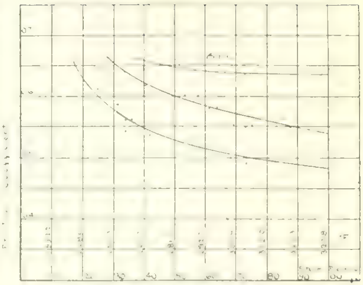


Fig. 6, Oil C.

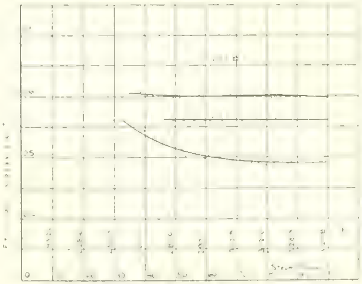


Fig. 7, Oil D

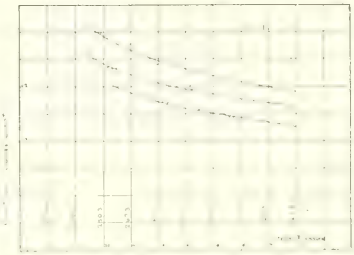


Fig. 8, Oil E.

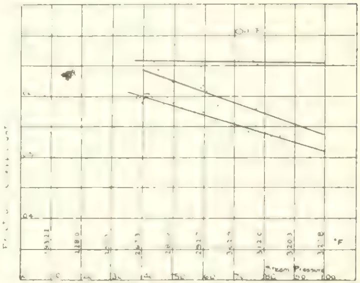


Fig. 9, Oil F.

VARIATION OF THE FRICTION COEFFICIENT WITH STEAM PRESSURE AND TEMPERATURE.

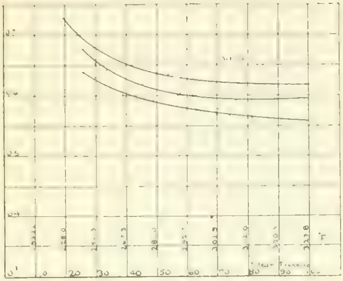


Fig. 10, Oil G.

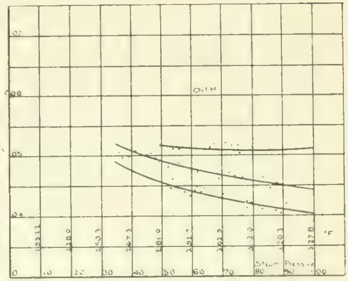


Fig. 11, Oil H.

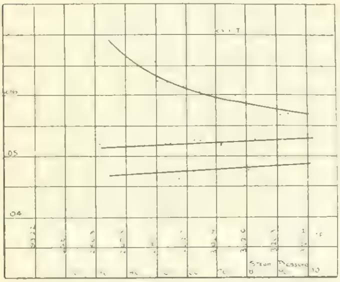


Fig. 12, Oil I.

VARIATION OF THE FRICTION COEFFICIENT WITH STEAM PRESSURE AND TEMPERATURE

According to the value of friction coefficient, based on the same feed in seconds to the drop and for the same steam pressure, the oils rank as shown in the following tables:

TABLE 5.

Steam Pressure, 60 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0439	H	.0472	H	.0510
I	.0474	I	.0520	B	.0588
D	.0500	A	.0539	D	.0600
C	.0511	B	.0550	A	.0600
A	.0511	D	.0560	I	.0610
B	.0517	C	.0582	G	.0626
E	.0560	E	.0596	E	.0632
F	.0570	G	.0598	C	.0640
G	.0572	F	.0608	F	.0660

TABLE 6.

Steam Pressure, 80 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0418	H	.0452	H	.0510
I	.0480	I	.0523	B	.0569
D	.0490	A	.0529	I	.0585
C	.0493	B	.0533	A	.0598
A	.0500	D	.0560	D	.0600
B	.0505	C	.0567	E	.0608
E	.0540	F	.0573	G	.0618
F	.0540	E	.0580	C	.0640
G	.0560	G	.0590	F	.0660

TABLE 7.

Steam Pressure, 100 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0404	H	.0438	H	.0510
I	.0485	B	.0525	B	.0558
C	.0485	A	.0526	I	.0567
D	.0490	I	.0528	E	.0591
A	.0495	F	.0535	A	.0598
B	.0502	C	.0542	D	.0600
F	.0510	E	.0572	G	.0618
E	.0528	D	.0560	C	.0640
G	.0560	G	.0590	F	.0660

It appeared to writer that a comparison of the lubricating qualities of the oils on the basis of the same rate of feed in drops per minute, is not entirely reasonable on account of the fact that different oils have different size drops. Therefore even though the feed in number of drops per minute is the same, the quantity by volume admitted into the cylinder will not be same, and as a consequence the comparison is not a true one.

The friction coefficients of the oils should be compared on the basis of the same quantity by volume and with that end in view experiments were carried out to determine the size in cubic centimeters of the drops of the oils tested under the same conditions of feed in drops per minute, and at the same temperature of the oil in the lubricator as under the actual conditions of the friction tests described in the previous pages.

Size of Drops. The apparatus used to determine the size of the drops of the oils, was a lubricating cup, detached for this purpose from the friction testing apparatus, fitted with a graduated glass tube (a) filled with hot water, whereby the oil was warmed up to the proper temperature, and by means of which sufficient pressure was obtained to force the oil from the lubricating cup into another graduated glass tube (b), partially filled with water. The apparatus is shown in Fig. 13.

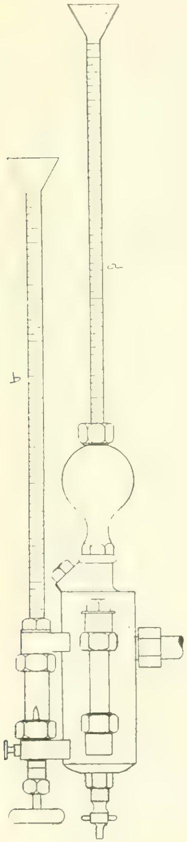


Fig. 13.

After adjusting the rate of feed to the required number of drops per minute, a certain counted number of drops of oil was let into the graduated glass tube (b) and their combined volume in cubic centimeters read.

The volume of the water in tube (a) which displaced the oil was also read, and as it is equal to the volume of oil displaced, the average value of these two volumes, namely that of the oil and that of the water displacing the oil divided by the number of drops, gave the size of the drop in cubic centimeters.

The average size of the drops of the oils, as measured by the above described method, is given in the following table:

TABLE 8.

Oil	Size of drops
A	.3124 c. c
B	.2423
C	.2142
D	.1911
E	.1653
F	.1482
G	.1418
H	.1184
I	.0722

From the size of drops, as given in the above table, and the rate of feed in drops per minute, the quantity of oil admitted into the cylinder for various rates of feed was calculated and the results embodied in the following curve (Fig. 14), where the volume per minute is plotted as a function of the rate of feed in seconds to the drop.

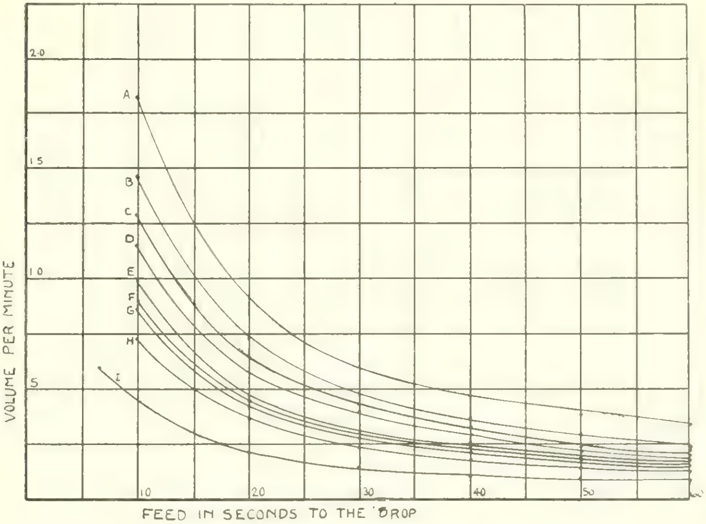


Fig. 14.

VARIATION OF THE FRICTION COEFFICIENT WITH RATE OF FEED IN SECONDS PER DROP.

In order to translate the results of the friction tests on the basis of equal rates of feed, in terms of equal volumes of oil admitted into the cylinder in unit time, we need besides the above curves showing the variation of the volume of oil with the rate of feed, also curves showing the variation of the friction coefficient with the rate of feed in seconds to the drop, or drops per minute.

Accordingly the following curves, Figs. 15 to 23, showing the friction coefficient as a function of the rate of feed in seconds to drop for constant pressure, were obtained from the friction coefficient curves plotted against steam pressure.

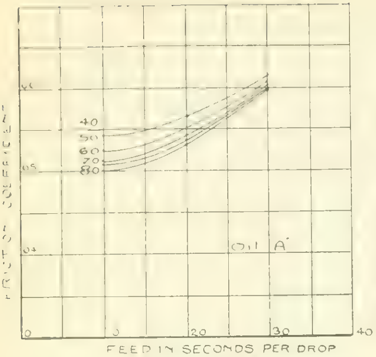


Fig. 15, Oil A.

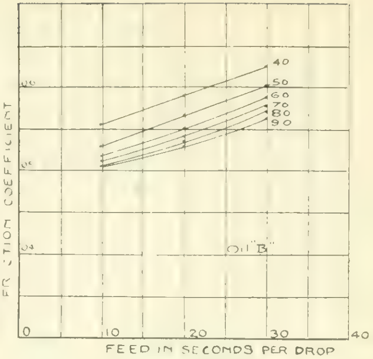


Fig. 16, Oil B.

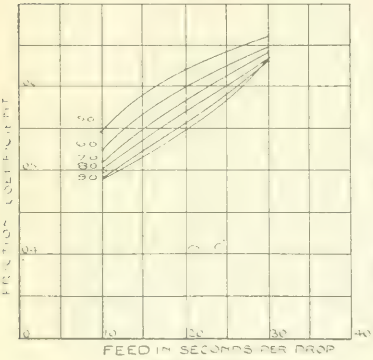


Fig. 17, Oil C.

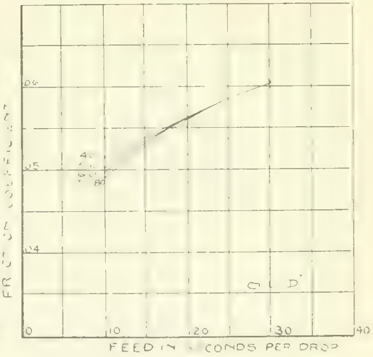


Fig. 18, Oil D.

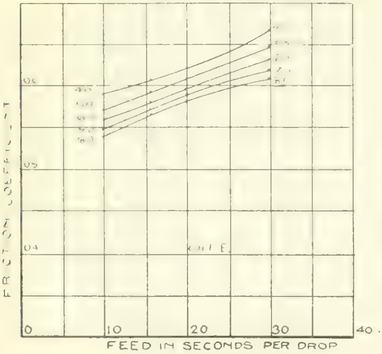


Fig. 19, Oil E.

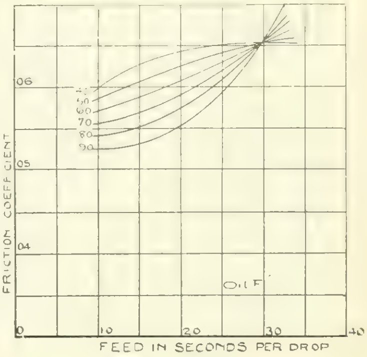


Fig. 20, Oil F.

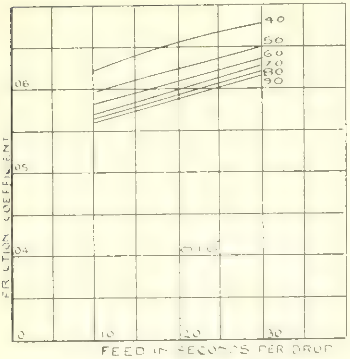


Fig. 21, Oil G.

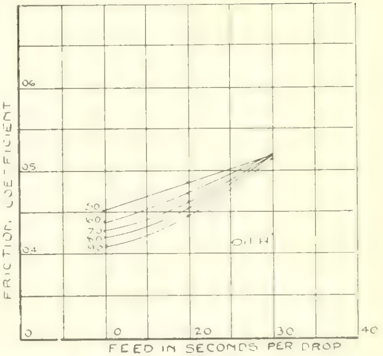


Fig. 22, Oil H.

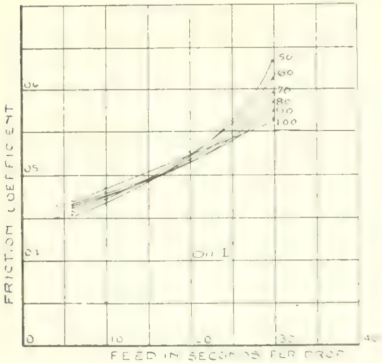


Fig. 23, Oil I.

VARIATION OF THE FRICTION COEFFICIENT WITH THE OIL FEED IN SECONDS PER DROP

These curves show certain peculiarities of the oils that are well worth some attention. Thus oils H and D while differing in many respects, have a more or less identical peculiarity, namely that the friction coefficient attains a constant value at a certain rate of feed, irrespective of the steam pressure. Oil H has a constant friction coefficient of .0520 at a feed of 2 drops per minute and oil D, a constant friction coefficient of .0560 at about 3 drops per minute.

Similarly oil F attains a constant friction coefficient of .0655 at a feed of 2 drops per minute, while the point of constant friction coefficient is not so well defined for oil I. However, these last two oils differ from oils D and H in the fact that for feeds higher than the feed for constant friction, the friction coefficient is higher for higher steam pressures and lower for lower steam pressures, the reverse being true for lower rates of feed beyond that for the constant friction coefficient value.

These rather curious results were not obtained for the other oils tested.

A quantity of .60 cubic centimeters of oil, corresponding to 2 drops per minute for oil A, was arbitrarily chosen as a standard for which the friction coefficient of the oils should be compared on the basis of equal volumes of oil admitted into the cylinder per minute.

From the curves of figure 14 we find, that in order to supply this quantity of oil per minute, the various oils tested would have to be fed at the following rates:

TABLE 9.

Volume of Oil Admitted into the Cylinder per Minute = .60 c c.

Oil	Rate of feed seconds per drop.
A	30
B	24
C	21
D	19
E	16
F	15
G	14
H	12
I	7

Using these rates of feed and the curves showing the relation between the friction coefficient and the rate of feed in seconds to the drop, (figs. 15 to 23), we can then find the corresponding friction coefficient of the oils for various steam pressures at a constant feed of .60 cubic centimeters per minute.

The following table shows the comparative values of the friction coefficient on this basis:

TABLE 10.

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "A" 30 sec. per drop	Oil "B" 24 sec. per drop	Oil "C" 21 sec. per drop
40	0.0613	0.0601	0.0625
50	.0607	.0580	.0600
60	.0600	.0562	.0590
70	.0600	.0552	.0570
80	.0600	.0545	.0557
90	——	.0540	.0550
100	.0590	.0535	.0540

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "D" 19 sec. per drop	Oil "E" 16 sec. per drop	Oil "F" 15 sec. per drop
40	——	0.0608	0.0630
50	0.0557	.0593	.0609
60	.0555	.0581	.0587
70	.0555	.0575	.0570
80	.0555	.0569	.0552
90	.0555	——	.0532
100	.0555	.0555	.0512

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "G" 14 sec. per drop	Oil "H" 12 sec. per drop	Oil "I" 7 sec. per drop
40	0.0608	——	——
50	.0592	0.0460	0.0460
60	.0582	.0444	.0462
70	.0578	.0432	.0468
80	——	.0424	.0470
90	.0572	.0415	.0472
100	.0571	.0410	.0475

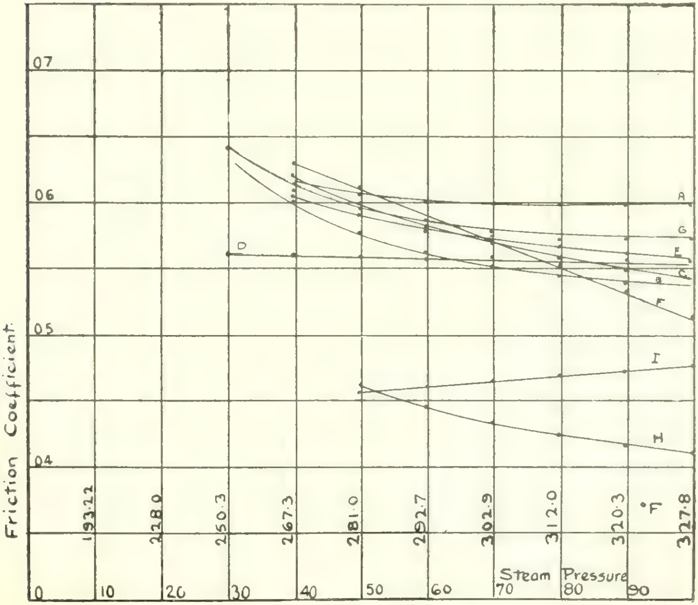


Fig. 24.

These results are also shown graphically in fig. 24. From these curves we can readily see that on the basis of the same quantity of .60 cubic centimeters of oil admitted into the cylinder per minute, the oils tested rank as follows for a steam pressure of 100 pounds per square inch.

TABLE 11

No.	Oil	Frict. Coeff.
1	H	.0410
2	I	.0475
3	F	.0512
4	B	.0535
5	C	.0540
6	E	.0555
7	D	.0555
8	G	.0571
9	A	.0590

MONEY VALUE OF THE OILS TESTED.

The question that the operating engineer frequently asks himself is whether a proposed change of cylinder oils would be profitable, in other words, whether the cost of operation would thereby be reduced and to what extent this change of oils will affect the operating expenses.

At present, in the absence of reliable information on the lubricating values of cylinder oils, the method generally followed by operating engineers is, after comparing the market prices, to buy a certain brand of oil at the best rate obtainable, try it for a certain time on his engine and if it does not produce any ill effects after a reasonable time, to continue to use it, assuming it to be a good oil. But the question whether he has gained by this change or not, whether the operating expenses have been decreased or actually increased is not at all settled.

According to a paper on "The Theory of Finances of Lubrication" presented before the American Society of Mechanical Engineers by the late Professor Robert H. Thurston,* it is absolutely necessary to ascertain every item of expense affected by the proposed change.

These items of expense are classified by Prof. Thurston as follows:

(1) "The cost of power produced, only to be wasted by that of friction."

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(2) "The expense incurred in wear and tear of the running parts, and in the replacement of parts destroyed, either by direct strains, or by gradual tear due to such exceptional resistances as are the effect of excessive friction."

(3) "The casual, indirect and often unperceived yet none the less serious losses throughout the system which are not included in the above."

(4) "The cost of the lubricating material applied for the purpose of ameliorating these losses."

The first item depends largely upon the cost and character of the fuel, type and size of the engine, the locality where the plant is situated, interest on the capital invested, depreciation, wages and insurance. The actual cost of producing one horse power per year may be as low as $30.00 and as high as $120.00 and in the following pages $80.00 was assumed as a fair estimate of the cost of production per horse power per annum.

The second and third items of expense cannot be estimated in dollars and cents with any degree of accuracy as they depend upon variable and generally unforeseen circumstances. As a rule these two items are included in the first item of expense as depreciation, and as a consequence their value, whatever it might be, is included in our assumed $80.00 per horse power per year.

If a proposed change in cylinder oil is desirable from the standpoint of economy, the money values of the oils should be determined by not only comparing the quantities and the cost of these quantities of oils used for a specified time, but also the other expenses incurred by using one oil instead of another.

In view of these briefly discussed considerations, the oils tested have been compared as to their money value assuming them to be used on a 70 horse power engine, and the results are given below:

Size of engine..............70 H. P.............13 x 13
Cylinder circumference .... π x 13 = 40.82 in.
Ring diameter .... 13.25 in.
Ring circumference .... π x 13.25 = 41.65 in.
Spring tension 3 pounds per inch circumference.
Tension per ring ....3 x 41.65 = 124.95 pounds
Tension for the 3 rings...........................373.85 pounds
Weight of piston ....110.00 pounds
Weight of piston rod .... 18.00 pounds
Total normal pressure ....510.85 pounds
Speed of engine ....275 revolutions per minute
Piston speed .... $\frac{275 \times 2 \times 13}{12}$ = 596 feet per minute

Steam pressure 100 pounds per sq. in. gauge.
Horse power loss in the cylinder due to friction:

$$\text{H. P.} = \frac{510.85 \text{ x } 596}{33000} \text{ x friction cofficient}$$

H. P. loss in the cylinder = 9.23 x friction coefficient.
Quantity of oil in gallons per year of 360 days = 136.86 x s x d
where s = size of the oil drop in cubic centimeters.
d = drops of oil admitted into the cylinder per minute.
hence s x d = volume of oil in c c. admitted into the cylinder per minute.

TABLE 12.

Rate of Feed = .60 c c. per minute.—Steam pressure = 100 pounds per sq. inch.

Oil	Gallons per year	Cost of Oil per Gal., cents	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
H	82	45	$36.90	.378	$29.40	$66.30
I	82	38	31.16	.438	35.00	66.16
F	82	48	39.36	.473	37.80	77.16
D	82	45	36.90	.512	41.00	77.90
C	82	59.5	48.79	.498	39.90	88.69
B	82	60	49.20	.494	39.50	88.70
E	82	60	49.20	.512	41.00	90.20
A	82	60	49.20	.545	43.50	92.70
G	82	65	53.30	.527	42.20	95.50

TABLE 13.

Rate of Feed = 2 drops per minute—Steam Pressure = 100 pounds per sq. inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	19.15	$ 7.75	.523	$42.00	$49.75
H	30.10	15.18	.469	37.50	52.68
F	39.96	18.85	.602	48.20	67.05
D	52.00	23.40	.550	44.00	67.40
G	37.90	24.60	.567	45.35	69.95
B	65.60	39.40	.514	41.20	80.60
C	57.50	34.20	.582	46.50	80.70
E	43.80	26.30	.544	43.50	89.80
A	82.00	49.20	.550	44.00	93.20

TABLE 14.

Rate of Feed = 3 drops per minute.—Steam pressure = 100 pounds per square inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	29.80	$11.52	.487	$39.00	$50.52
H	48.80	22.98	.405	32.40	55.38
F	61.00	28.80	.494	39.50	68.30
D	72.40	32.60	.516	41.30	73.90
E	62.50	37.50	.525	42.00	79.50
G	57.00	37.00	.544	43.50	80.50
C	86.80	51.64	.498	39.90	91.50
B	100.00	60.00	.484	38.90	98.90
A	123.00	73.75	.485	38.90	112.65

TABLE 15.

Rate of Feed = 6 drops per minute.—Steam pressure = 100 pounds per square inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	61.60	$33.40	.446	$35.60	$69.00
H	98.50	43.50	.373	29.80	73.30
F	123.00	59.00	.470	37.60	96.60
D	157.40	70.80	.452	35.90	106.70
G	116.20	75.60	.516	41.30	116.90
E	134.00	80.50	.488	39.10	119.60
C	174.00	103.50	.446	35.60	139.10
B	192.80	115.10	.462	36.90	152.00
A	249.00	149.00	.456	36.50	185.50

From the above tables, it is readily seen that from whatever standpoint we consider the oils, either on the basis of equal volumes of oil or equal rates in drops per minute, oils I and H rank higher than the other oils tested. These oils have in their favor, besides a low cost also a low friction coefficient and also a small drop as compared with the other oils, which when the comparison is made on the basis of equal rates of feed in drops per minute, is a deciding factor in their favor.

But besides the cost of the oil and the cost of the power loss due to friction, or a combination of the two, there is the actual behaviour of the oil in the engine which must be given some consideration. Thus, the oil may get gummy, or it may not distribute well over the surfaces to be lubricated, or it may contain a comparatively large amount of free acid or animal and vegetable fats, which to be sure reduce friction, but under the action of the high temperature in the cylinder will give off free acid that will attack the cylinder and in time corrode it.

Referring to table 4 we notice that oil H has the largest saponification number in comparison with the other oils, indicating that it is more apt to become gummy in the cylinder; it has also the largest per cent of animal and vegetable fats, similarly indicating that it will give off more free acid to corrode the cylinder.

As to oil I, we find that it has the largest free acid value (per cent oleic acid), besides having too small a drop, which in this instance may be considered a disadvantage, for on the basis of the same volume admitted into the cylinder, this oil will have to be fed at a pretty high rate, as compared with the other oils, and on the basis of equal rates of feed, the film of oil may not be sufficiently thick, especially as the viscosity of the oil decreases at higher temperature, and though the friction is decreased, it is decreased at the expense of the more rapid wear of the rubbing surfaces.

Oil F is the third in rank on the basis of cost. It has a low free acid value also a lower per cent animal and vegetable fat, which gives it a decided advantage over oils I and H.

Oil D does not differ very much from oil F, especially when the comparison is made on the basis of equal volumes and equal rates of two drops per minute. It is true that with two drops per minute, the necessary quantity of oil D is quite a good deal larger than the corresponding quantity of oil F on account of the difference in the size of the drops, but the friction coefficient of oil D is correspondingly smaller, resulting in a smaller amunt of power loss. Similarly, oil D contains a larger amount of free acid compared with oil F, but F has a larger per cent of animal and vegetable fats. All things considered then, there is not apparently much choice between these two oils for the rates of feed mentioned.

The other oils tested, although they have low acid values and low percent of animal and vegetable fats to their advantage, have correspondingly larger friction coefficients resulting in larger power loss, besides the higher cost and large size drops with increase in quantity for equal rates of feed, which is decidedly against them.

THE
UNIVERSITY OF MISSOURI
BULLETIN

ENGINEERING EXPERIMENT STATION SERIES
VOLUME 4 NUMBER 3

ARTESIAN WATER IN MISSOURI

BY

A. W. McCoy

MDCCCXXXIX

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
September, 1913

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and two research assistants together with a number of teachers who have voluntarily undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

STUDY OF ARTESIAN WATER IN MISSOURI

INTRODUCTION

An artesian well may be defined as a vertical well in which the water rises near to or above the surface.

It is the purpose of this bulletin to outline the general artesian conditions in Missouri. Technical terms have been omitted and the facts studied have been stated as clearly as possible so that every one may get the fundamental points. Anyone wishing to study artesian waters more fully will find the best authorities listed in the bibliography.

In the investigation of the artesian water conditions of Missouri the county was made the areal unit and about thirty counties were visited and studied. Data from the remaining counties was obtained from officials of the principal towns, well drillers and private individuals interested in the work. Owing to the limited amount of time only a few days could be given to each county studied; and unfortunately the field work had to be done largely during the spring when the weather conditions were unfavorable for geological work. However, the operation of the deep wells was readily studied, and especial effort was made to visit the operating wells in several counties. Data as to depth, diameter, amount of water pumped, and approximate economical conditions were best obtained from the engineers in charge of the operation. Material both published and unpublished on Missouri conditions has been used freely.

The line of demarcation between artesian waters and surface waters is not every where exact, and is difficult to determine in some localities. The artesian waters of Missouri rise from a few principal formations of early Paleozoic age. Since the water conditions of these formations are fairly uniform over areas underlain by the water bearing strata, it is obvious that these waters are the most important and should be investigated first. Surface waters, owing to the variable factors of each locality, demand detailed study and consequently have been left for future work. Artesian waters become surface waters where the water bearing formations outcrop, but fortunately these areas are not extensive so that over the greater part of Missouri artesian waters are generally distinct from the surface waters.

Scientific investigation of deep wells has been greatly needed in Missouri. Although Dr. E. M. Shepard's work on Missouri underground waters has been put before the people, city councils considering municipal water supplies still continue to visit and study neighboring communities having deep wells. The information thus obtained may in some cases prove valuable but at all times is indefinite and frequently misleading. The sources for efficient town or corporation supplies lie far below those of common wells and unless the local driller is familiar with the exact conditions, only approximate estimates can be furnished the prospector. Scientific knowledge of both general and local conditions makes it possible to offer new suggestions as to better sources of water and better methods of utilization.

The object of this investigation is to furnish the communities underlain by the principal water bearing formations some more or less exact data as to possible deep wells, that is, to show at what depths water may be reached, how high it will rise in the well, through what formations the drill must pass, what compounds the water is liable to contain, amount of discharge from the ordinary well, and the general economical conditions as compared with other sources.

Artesian water conditions are closely related to the geological structure of the locality. They vary according to altitude of the well site, the dip, texture and depth below the surface of the water bearing rock, and the distance from the outcrop of the same. Consequently the study of the geological conditions is of primary importance. Investigation of the outcrops of the water bearing rocks gives excellent information concerning their thickness and character and the relation of the overlying and underlying beds. The general dip may offer some idea of the depth at which such rocks may be struck in another locality. However, over an area as large as Missouri, formations dipping below the surface may be expected to become thicker or thinner and often pinch out and are replaced by different formations. The composition and texture of the formation is likely to change materially so that neighboring localities may obtain different waters from the same stratum. Local warpings not shown at the surface have a decided effect upon the water conditions and otherwise work against the general geologic evidence at the surface.

For these reasons the investigation of the deep water bearing formations must not be based on the surface geology alone, but also upon the data from the deep drill holes. Drillers' logs and sample cuttings are the source of this information. From these data attempts are made to correlate the strata penetrated, by knowing the surface conditions, the distance to the outcrops of the water horizons and the general dip of the same. By connecting well sections of different localities cross-sections may be made showing the relations of the various formations across the state. Examples of these are shown in the accompanying plates.

The geologic evidence of deep underlying strata must come from records and samples of the drillings collected when the well is being drilled. In most cases these are not definite and have many possibilities of error. The driller often is careless in his record, sometimes failing to observe the important changes in the character of the beds penetrated, either because they are not easily recognized or perhaps have no direct effect on the water level in the well. Again the material of higher levels is constantly falling into the hole as it is drilled. The cuttings often show a great range of foreign material for beds at a certain depth. For example coal or shaly particles often are brought up with cuttings from crystalline limestone of the underlying rock known to be free from coal. Moreover a caving sand of a higher stratum may impregnate the magnesian limestone cuttings in a lower formation. Drilling data are liable to be the observation of persons not familiar with the character of cuttings and consequently questionable. The investigator can only take information of this kind and give it its proportionate weight and base his correlation of strata accordingly. In some cases corporations or individuals have realized the scientific importance of these records and have kept a complete list of the well cuttings. In most cases, unfortunately, no records have been saved or such incomplete ones that they are practically worthless. With such limited information for scientific research only approximations can be reached in this report. It will take careful observation and study for many years to make a thoroughly reliable report possible.

The most valuable record, geologically, of a deep well is a complete list of samples or cuttings obtained on the ground at the time of the drilling. These when carefully labeled with the depth from the surface at which they were obtained furnish an authentic succession of the various formations. Drillers are very apt to make mistakes in labeling or gathering samples after a considerable amount of cuttings have been obtained. Often several hundred feet of limestone are mistaken for the same formation and consequently it is necessary that samples should be taken every few feet. Also samples from every noticeable change should be taken. Professor W. H. Norton of the Iowa Geological Survey gives the following directions* for taking samples:

"For all scientific purposes samples should be taken directly from the sand pump at every five or ten feet, at the end of a cleaning out, and at every change of stratum. They should be placed unwashed, in wide-mouthed bottles or glass jars (one to four ounce bottles are large enough) and plainly and accurately labeled in india ink with the names of the town or other location, and of the owner, the date, and the depth from which each was taken."

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*Iowa Geological Survey. Vol. 21, p. 37.

In working over the cuttings for this report all were examined with a hand lens and some were studied under the microscope in order to identify more specific characteristics. Limestones were tested with cold hydrochloric acid and in cases where there was free effervescense it was assumed that the limestone was nearly pure unless chert or other foreign material could be determined with the lens. Slow effervescence when materially aided by heating was taken to designate magnesian carbonate. It was not considered necessary to determine the relative amounts of the different compounds or ingredients.

Even when the well cuttings are carefully saved there is still a possibility of error in completely correlating the various strata. In most cases too few samples are taken for a complete geological succession. Thin strata are often passed through unnoticed. The slush bucket may not carry up the cuttings of just one elevation alone but a mixture of all material that might have fallen from above during the last drilling.

After a set of well cuttings have been individually worked out, the correlation of strata with that of neighboring regions follows. One of the best means to determine the age of any rock is by the fossils it contains. However, in well cuttings the rock is usually crushed so badly that no recognizable fossils remain. The smaller fossils have some chance of escape but none were used as a means of correlation in this work.

Similarity of the rock is the most important method of connecting like strata. That is, correlating beds of like composition, structure, hardness, color, etc. For instance, the coal and shale beds in the coal measures do not correspond with the white crystalline limestones of the Mississippian, and are readily differentiated from them. These white cherty limestones likewise differ from the thin shaly limestones and sandstones of the Devonian. The Joachim formation, which is found in many Missouri well sections, is characteristically uniform, is marked by the absence of chert, and has the appearance of "cotton" rock. This is the first magnesian limestone encountered and consequently is an excellent horizon marker. The St. Peters sandstone is usually softer, coarser grained and less colored than the Roubidoux although the best method of distinction is by the relation to over-lying rock. If a sand is overlain by 100 or 150 feet of magnesian limestone it is most likely the Roubidoux sandstone, as the formation above (the Jefferson City) is the first thick magnesian limestone. The Jefferson City formation contains chert and sand and consequently is not easily mistaken for the

Joachim which is a thin, pure magnesian limestone. After the Ozarkian series is reached little use is made of lithological characteristics as the whole upper part of the series consists of sandy magnesian carbonates. Above the Ozarkian, however, this method of correlation estimated one which may outcrop some 50 miles or more away.

Another decided help to interpreting drillings is the known dip of the strata. Having the geologic map of Missouri, and the elevation of the outcrop and well site, the angle of dip completes the necessary data for finding the depth at which any bed may be found. Of course this computation assumes that local upwarpings and downwarpings are negligible and that the outcropping beds continue with the same thickness and dip. Sags and swells, thickenings and thinnings all are important in the exact location of underground strata, so that estimated depths may sometimes vary from 100 to 200 feet. However, in cases where the strata is comparatively uniform very close approximations may be made. Consequently when one formation is estimated to be reached at 750 feet below the surface at "A" and a similar formation is found at 800 feet, it is safe to assume that the formation occurring in the well at 800 feet is the same as the estimated one which may outcrop some 50 miles or more away.

The order of succession of strata is also an effective aid in working out well cuttings. The older formations occur at the bottom directly upon the granite floor and are succeeded by younger formations wherever they occur. In many cases formations occur only in limited areas of the state and consequently breaks in the succession according to locality are always looked for. For example, the Ordovician and Silurian rocks are almost entirely absent on the west side of the Ozarks and the limestones of the Ozarkian series occur directly below the Devonian shales and sands in the well sections.

The difficulties in drawing exact boundary lines between formations are noticeable. Often beds merge into others with the same composition and nearly the same structure so that it is hard to distinguish the difference in the field along the outcrop. Then again the variation of beds back underground from the outcrop may cause differences in the well section from that which might be expected. The meagre data, the uncertainty of conditions and the nature of the evidence acquired in so short a time necessarily impresses the possibilities of future change.

In response to the requests that have been made concerning forecasts of where and at what depths water may be found, a short part of this bulletin will be devoted to such approximations for different parts of the state. Under each of the county summaries something of this nature will be inserted in order that towns considering water supply from deep wells may have some idea of the existing conditions. In using these forecasts as a basis for estimation it must be understood that they are only approximate and just as nearly correct as a nine months' study will permit. However, enough is known of the deeper rock formations of Missouri to allow serious consideration of the deep well possibilities, and the forecasts put forward later may be used as approximate estimates.

The writer is greatly indebted to the courtesy of many people of Missouri and elsewhere. The commercial clubs of the state have afforded excellent opportunity for free correspondence concerning artesian conditions in different localities. Several railroads have generously furnished well logs and other data of value. Private corporations have offered assistance which has materially aided the work. Contractors and drillers have placed at our service the logs and cuttings of many wells, and in every case have been willing to save samples of wells being drilled. Several private citizens have taken a decided interest in this work and have furnished notes and in some cases private collections of well cuttings. For all these the writer is very thankful, and sincerely hopes that the bulletin may prove of service to them.

Especial acknowledgement is due Dr. E. B. Branson under whose direction the work was carried out. It was his investigation that first questioned the nomenclature of Missouri sandstones and by his suggestion the evidences for the mistake were brought out in this report. Professor T. J. Rodhouse largely furnished the information for the cost and adequacy of deep well supply.

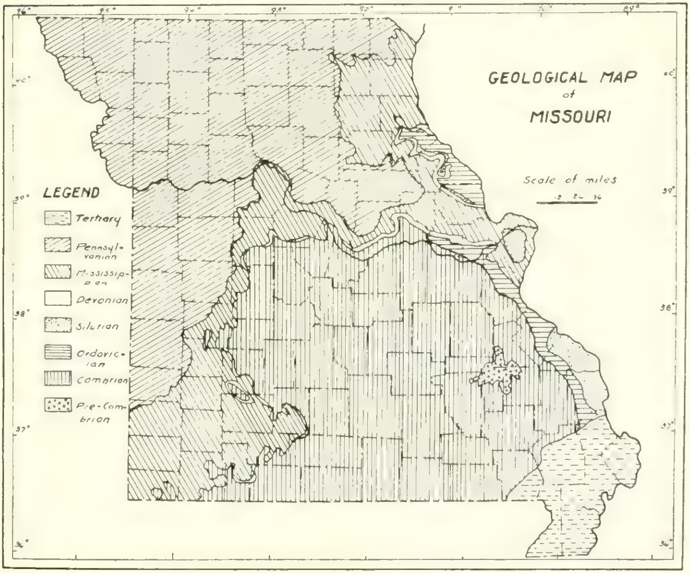
CHAPTER I.

THE OCCURRENCE AND DESCRIPTION OF THE WATER BEARING FORMATIONS

The deep water supply areas of Missouri studied in this work may be divided into three provinces:

1. The area underlain by the St. Peters sandstone.
2. The area underlain by the Roubidoux formation.
3. The area underlain by the Gasconade formation.

The rocks in Missouri vary from the oldest known up to the most recent, though several periods are not represented. The St. Francis Mountains are largely made up of igneous rocks which represent the oldest or Pre-Cambrian series. These rocks are porphyries and granites and occur mainly in St. Francis, Iron and Madison counties. They form a nucleus around which the younger formations occur with the exception of the more recent formations of the



southeastern lowlands.

The section on page 11 gives a general idea of the sedimentary rocks that successively overlap the older formations. This section represents only approximate thicknesses and attempts to take in all the formations that occur generally to the north and west of the Ozarks. The thicknesses were taken from Buckley's* estimates, and from observations of a number of well sections. Many formations have not been shown because of their local nature, and others are shown thin because of a thinning tendency in the well section. This section is only to give the prospector and well driller some idea of the rocks that he will be most likely to penetrate. In using this section it is necessary first to determine the surface rock from a geologic map and then find the corresponding location of the surface on the section.

FIRST PROVINCE

The St. Peters sandstone underlies continuously the northeastern corner of Missouri. The southwestern boundary of this area seems to run from Crystal City through Pacific, approximately straight across to Moberly and from there north and northwest into Iowa. St Peters sandstone is found in many places in central Missouri and has often been supposed to occur in the southwestern part of the state but the well sections show that no wells out of the above named area furnish suitable water from the St. Peter sandstone. This sandstone may underlie the younger strata completely around the Ozarks, but not in such a manner as to supply deep wells.

In southern Boone and Callaway counties and also in Pettis County a sandstone similar to the St. Peters and in the proper place geologically, has been observed filling synclines or sags in the Jefferson City limestone. This indicates that the St. Peters sandstone was eroded from the central area before the younger rocks were formed. The Wabash Railroad well at Moberly is the farthest west of the wells obtaining water from the St. Peters sandstone. It was reached at 642 feet below the surface, and only 15 or 20 feet of sand is passed through in that vicinity.

There is a decided basin in the St. Louis region and a thickening of the formations over the St. Peters sandstone. In the Belcher Well at St. Louis there are some 1500 feet of sediment above the sandstone. This is peculiar to the St. Louis vicinity as the depth to the St. Peters sandstone varies from 200 to 1000 feet below the surface from the southern extremity of its area to the Iowa border respectively.

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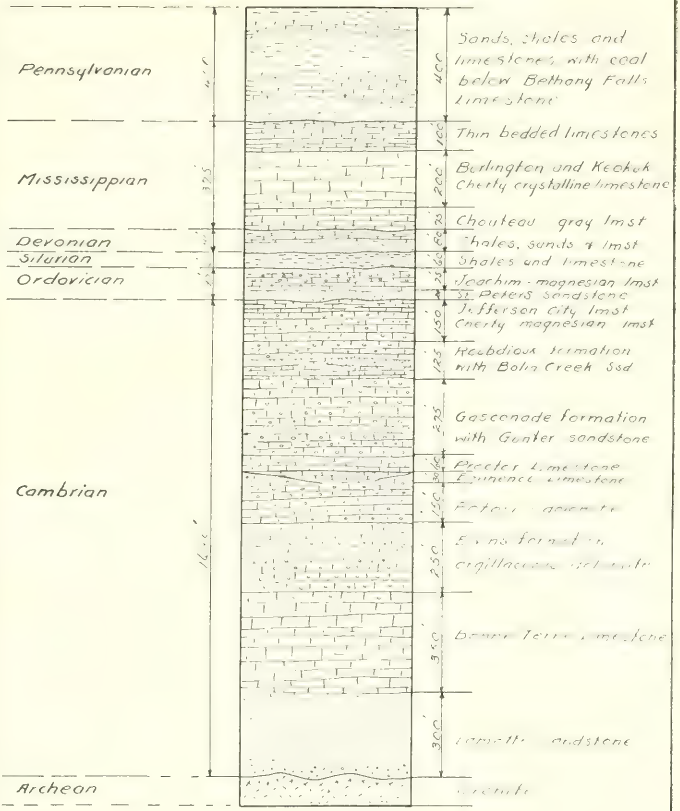
*Missouri Bureau of Geology and Mines, Vol. IX.



GENERAL SECTION

FOR NORTH-CENTRAL AND SOUTHWEST MISSOURI.

Scale 1"=300.

The St. Peters is a loosely cemented sand, with the grains rather uniform in size and usually larger and more rounded than the grains of the older sandstones. The color is white except in places where particles of scattered iron rust have stained the stone brown or red. Stratification lines are absent and the ill-defined bedding planes are 10 feet or more apart. In thickness it varies from nothing to 200 feet. It outcrops at Crystal City, about 30 miles south of St. Louis, and also at Pacific about the same distance west. Smaller outcrops can be traced through Warren and Montgomery counties. In southern Callaway and Boone Counties this formation pinches out and the Joachim limestone rests directly upon the Jefferson City limestone.

The structure of the St. Peters sandstone is open and porous due to the well rounded grains of sand with little cementing material. The smoothness of the grains reduces friction to a minimum so that water may freely pass through the formation.

Some irregularities in northeastern Missouri, both in thickness of overlying strata and in the structure of the country rock, cause the study of the St. Peters to be complex. For example, a fold through Pike and Ralls counties raises the formation a hundred feet or more above the calculated elevation. Sufficient detailed information has not yet been obtained to follow out the exact effects of these folds and faults.

The water from this formation is comparatively pure and soft in the south and eastern parts of the district, due to the absence of soluble matter both in the grains and cement, but becomes impregnated with salt and sulphur in the north and west. Along the Mississippi River through Pike, Ralls and Lincoln counties many of the farm wells reach excellent water from this sandstone within a few hundred feet of the surface.

SECOND PROVINCE

The inner border of the Roubidoux province runs approximately through Gasconade, Cole, Morgan, Hickory, Polk, Webster and Stone counties. The area includes all southwestern Missouri as far north as Kansas City, and all north central Missouri south of Livingston, Linn and Randolph counties.

The Roubidoux outcrops in Morgan and Miller counties and swings around the Ozarks through the counties in south central Missouri. All the north central and southwestern parts of the state are underlain by it. It is one of the most important water horizons in the state and a large number of the deep wells in this area receive water from it.

The Roubidoux sand consists of fine grained, well rounded, iron stained quartz fragments. The sand beds are not continuous but occur in more or less lens shaped layers, being connected by porous cherty beds. The limestone is a porous magnesian lime and conducts the water just as well if not better than the sand. The average thickness of the Roubidoux formation is about 100 or 125 feet.

In the Columbia wells the water comes both from the sand and the limestone. One of the city wells did not strike any appreciable sandstone, but after fifty feet more of limestone had been drilled through its flow was as large as that of other wells within a few hundred feet that encountered sand. In the Carpenter-Schaffer well at Joplin, the sand did not furnish enough water, but one hundred feet of limestone below the sand carried a sufficient supply.

The water from the Roubidoux formation varies according to the locality. In Columbia it is comparatively hard, free from contamination, and excellent for domestic purposes. It is not especially good for boilers but by cleaning them every two or three weeks the scale is kept well under control. The water at Fulton is almost the same, but contains a compound that forms a hard scale in the water pipes, especially where the water is heated. The Carthage and Webb City wells furnish excellent water for almost every use demanded though it is a little hard. Joplin wells seem to contain a magnesian compound which is injurious to pipes and boilers. The water from the Clinton wells contains sulphur but no trouble is noticed commercially on that account. The Nevada Water Co. is bothered with the scale that forms in the meters; practically only one style of meter can be used, and repairs are necessarily frequent.

The Roubidoux elevation varies within its stated area of supply from 500 or 600 feet above sea level to 400 or 500 feet below sea level. This makes it possible to reach the formation from 200 to 500 feet from the surface along the border next to the Ozarks, and varying from there proportionally to 1000 or 1400 feet from the surface on the western and northern limits. No dry wells have been reported in the known Roubidoux area, and the wells have so nearly the same characteristics that it is safe to assume that the Roubidoux is continuous under the stated province and is a sure water horizon.

THIRD PROVINCE

The inner boundary of the area underlain by the Gasconade formation extends approximately from Washington, Crawford and Phelps counties on the north, south through Texas and Shannon counties to the southern border of the state. The outer border extends up to and overlaps the inner border of the Roubidoux area.

This does not indicate that wells may not obtain a sufficient supply of water from the Gasconade formation outside this area, but that the wells outside generally obtain their water from one of the formations nearer the surface. Often a well is drilled through the Roubidoux rock to obtain reinforcement from the Gasconade.

The water in this formation percolates through broken cherty beds and sandstone members. The lower sandstones of the Ozarkian formations are characteristically variable, wedging in and pinching out, but the porous limestone and broken cherts seem to be excellent water conductors. The Gunter sandstone is a continuous member and is important in the transportation of water. The water is similar to that of the Roubidoux as the two formations are closely related. The city supplies for the deep wells at Rolla, Lebanon and a number of smaller places are from this formation.

A number of wells in the state obtain water from local lenses of sandstone throughout various formations, but no definite work has been done with these since they did not belong to one of the three main divisions studied.

CHAPTER II.

CONDITIONS IN THE NORTHEASTERN DISTRICT

The northeastern district includes the area north of the Missouri River and east of Adair, Macon, and Randolph counties. The artesian conditions are not favorable throughout the entire area, but are especially good in the counties bordering the Mississippi River. The St. Peters sandstone is supposed to underlie this region but varies so widely within the area that the meagre records do not form a complete chain of evidence. The rocks dip to the west and north, the St. Peters sandstone rising steadily from the Iowa border. The eastern tier of counties has the most favorable location for artesian water because of the lower altitude of the surface and the relative rise in elevation of the St. Peters sandstone underlying them. A number of flowing wells are reported from this part of the district; Canton and LaGrange in Lewis County; Hannibal, Nelsonville and Oakwood, in Marion County; Spalding in Ralls County, and Louisiana in Pike County.

The deep well water in this region is variable and many waters are highly impregnated with salt and sulphur. This is probably due to the distance the water has traveled underground, and to local variations in mineral composition of the rocks encountered.

In the western and northern part the water is usually so burdened with mineral matter as to make it rather unsuitable for domestic purposes, but generally in the eastern and southern parts the quality is satisfactory.

In the following paragraphs the conditions in a number of counties are described and well logs given. Unless definitely stated otherwise the reader may assume uniform conditions throughout the county.

ADAIR COUNTY

Some years ago a well was sunk at Kirksville for the purpose of obtaining a city supply. The depth of this well is 1290 feet; the principal water comes from about 1150 feet and stands within 240 feet of the surface. It is highly impregnated with iron and sulphur and probably comes from the St. Peters sandstone but as only an imperfect record* of the well was kept this cannot be determined with certainty.

AUDRAIN COUNTY

A number of wells have been drilled in central and eastern Audrain County, the depths averaging from 150 to 500 feet. Abund-

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*U. S. Geological Survey Water Supply Paper No. 195, p. 55.

Wells in Audrain County.

Location	Owner	Contractor	Driller	Depth in Feet	Diam. in Inches	Depth to the Principal Water. Feet	Yield in Gallons per minute		Elevation above Sea Level. feet		Remarks
							Flow	Pumped	Water Level	Well Site	
5 1-2 miles N. E. of Clark	Geo. E. Ess	Johnston Bros.	Johnston Bros	216	5 1-2	190				874	
3 miles S. of Laddonia	W. T. Hughlett		D. F. Palmer	150	4	100		2	740	790	
Mexico			W. E. Smith	480						800	
5 miles N. of Mexico	Earl Carter	W. E. Smith	W. E. Smith	410	5 5-8	400		5	730	810	
1 mile N. of Mexico	Jas. Johnston	W. E. Smith	W. E. Smith	227	5 5-8	190		2	750	800	
6 miles N. of Mexico	Jas. Johnston			136	4			5			
2 miles E. of Mexico	Lawder Estate		R. J. Lawder	320	8	265			670	820	
8 miles N. of Vandalia	O. L. Fuque	G. W. Calvert	W. D. McDonald	306	6	280			674	780	
Vandalia	J. K. Moore		W. D. McDonald	290		290			685	775	
Mexico	Mexico City			1025	6	880					City water supply
Vandalia	Vandalia City			685	8	685		35	680	770	City water supply

ance of hard water rises within 50 or 75 feet of the surface and this provides excellent farm supplies.

The Water Works Company of Mexico drilled a well 1050 feet deep and a record was kept by the late Prof. G. C. Broadhead. The well is no longer used for city supply.

Log of Waterworks Well at Mexico, Mo.

	Depth in feet	Character of Rock. Remarks.
Pennsylvanian	15-25	Limestone, fragments of gray quartz or gravel
	35	Limestone, soft, drab, earthy
	50	Limestone, darker and harder, with black shale
	52	Black shale
	58	Limestone, soft, light bluish gray
	65	Limestone, light bluish gray
	70	Shale, black bituminous
	95	Limestone, fine grained, hard, dark fragments, gray
	100	Limestone, fine grained, soft, light gray, with fragments of black shale
	120	Limestone, fine grained, soft, light gray, with fragments of black shale
	140	Limestone, fine grained, soft, light gray, no shale
	145	Coal, bituminous
Mississippian	160	Chert, hard, gray with yellowish coating on some fragments
	165	Chert, hard, gray hornstone, some white and opaque
	180	Chert, hard, gray hornstone, some white and opaque
	200	Chert, hard, gray hornstone, some white and opaque
	220	Limestone, gray, compact, mixed with considerable chert
	240	Limestone, gray, compact, mixed with considerable chert and some black shale
	260	Limestone, gray, compact, with considerable white opaque chert
	270	Limestone, gray, compact, with considerable white opaque chert
	285	Limestone, white crystaline
	300	Limestone, dark brown, compact
	315	Limestone, dark brown, compact, much chert
	340	Limestone, light gray, compact and much chert
	345	Limestone, dark gray, compact, earthy
	360	Limestone, dark gray, compact, earthy
	380	Limestone, dark gray, compact, earthy
	400	Limestone, dark gray, compact, earthy.
	425	Limestone, dark gray, compact, earthy, considerable chert
	440	Limestone, crushed to white powder, effervesced freely
	450	Limestone, grayish crystaline
Probable Devonian, Silurian, and Ordovician	485	Sandstone, rounded white transparent quartz, some limestone and chert
	515	Sandstone, rounded white, transparent quartz, some limestone and chert
	530	Sandstone, rounded white transparent quartz, some limestone and chert.
	565	Limestone, light gray, soft earthy
	600	Limestone, light gray, soft, considerable green shale
	630	Limestone, light gray, soft, less shale
	670	Sandstone, white quartz, some white chert, gray limestone and green shale
	680	Limestone, gray, compact, earthy, some green shale

Log of Waterworks Well at Mexico., Mo.—Continued.

	Dept in feet	Character of Rock. Remarks.
Probable Cambrian	705	Chert, white (iron stained) few grains of quartz sand
	720	Limestone, gray, compact, earthy, some green shale and chert
	800	Limestone, gray, compact, earthy, some green shale and chert
	820	Limestone, gray, compact, earthy, some green shale and chert
	840	Limestone, gray, compact, earthy, some green shale and chert
	860	Chert, some limestone and green shale
	870	Limestone in soft yellow-white powder
	880	Sandstone, white quartz considerable limestone
	970	Limestone, soft, gray
	1025	Limestone, in powder, soft white

CLARK COUNTY

There are two wells at Kahoka; one owned by the city, and the other by the Clark County Canning Company, Kahoka. The city well was drilled in 1901-2. It is 509 feet deep, the water rises within 90 feet of the surface, and the supply is wholesome and sufficient for the town of 2500 people.

The Canning Company's well is 360 feet deep and the water stands 72 feet below the surface. Several veins of water were struck in this well, and the supply seems to be of excellent quality.

The Santa Fe Railroad Company drilled a well at Wyaconda in 1911. It is 633 feet deep, but on account of an unfortunate experience with deep wells at Baring, Missouri it was thought unadvisable to drill deeper. The log on page 20 was obtained from the Railroad Company:

KNOX COUNTY

The Santa Fe Railroad put down a test well in 1902 at Baring to the depth of 894 feet. This well furnished salt water only. During the years 1911-12, the company made a thorough test, drilling 2125 feet. Water was obtained at several horizons, but was so impregnated with solid matter that it was too expensive to treat for boiler water. The St. Peters sandstone was struck at 944 feet in the deep well and 865 feet below the surface in the shallow one. A copy of the log of this well was furnished by the railroad company.

A well 523 feet deep was drilled 8 miles southwest of Knox City on a farm owned by Jack Rennen. The diameter of the hole is 4½

Log of Wyaconda Well.

Drilled in 1911; Walter Price, driller.

	Depth in feet	Character of Rock. Remarks.
Pennsylvanian	0 to 3	Soil
	3 to 65	Yellow clay
	65 to 105	Blue clay
	105 to 140	Yellow clay
	140 to 209	Blue clay
	209 to 218	Sand, a little water, 1½ bailer full after 40 minutes.
Mississippian	218 to 235	Blue clay
	235 to 260	Limestone
	260 to 264	Blue clay
	264 to 290	Limestone
	290 to 295	Blue clay
	295 to 341	Limestone
	341 to 390	Blue clay
	390 to 484	Shale, a little water between 460 and 484 feet.
	484 to 502	Sand rock
	502 to 518	Water bearing sand, 16 gals. a minute.
	518 to 598	Limestone
	598 to 603	Slate
	603 to 608	Shale
	608 to 628	Limestone
Devonian	628 to 633	Blue clay
	633	Plugged hole and abandoned well
		Well cased, 13 inch for 101 feet, 10 inch for 239 feet.

Log of Baring Well.

Drilled in 1911-12. First 1500 feet, Harris, driller; 1500 feet to 2125 feet, Shaffer, driller.

	Depth in feet	Character of Rock. Remarks.
Pleistocene	0 to 100	808 ft. above sea level. Blue clay
Mississippian	100 to 175	St. Louis limestone and Osage Group. Seap of water below 115 ft. 13" shoe at 115 feet.
	175 to 275	Chert, white limestone chalcedonic and crystalline silica.
	275 to 280	Green gray shale with irregular grains of crystalline quartz, calcareous.
	280 to 345	White limestone
	345 to 360	Very coarse sandstone
	360 to 375	Chert, fine sand of particles of cryptocrystalline silica, water bearing. Tested well, 65 gallons a minute.
	375 to 410	Light yellow marl, rapid effervescence.
	410 to 465	Light drab limestone
	465 to 498	Kinderhook shale; 10" shoe made a dry hole 310 feet above sea level.
Devonian	498 to 510	....
	510 to 745	Gray limestone, rapid effervescence, fossiliferous with joints of crinoid stems and fragments of shells of brachipods.

Log of Baring Well—Continued.

	Depth in feet.	Character of Rock. Remarks.
Silurian	715 to 860	93 feet above sea level; light yellow gray limestone, rapid effervescence, with fine grained sandstone; much cryptocrystalline silica in chips.
	860 to 865	White sand rock, a little water.
Ordovician	865 to 934	Dolomite
	934 to 938	Shale—126 feet below sea level
	938 to 944	Limestone—130 feet below sea level
	944 to 990	St. Peters sandstone—136 feet below sea level Light yellow pure quartz. Note.—This is the same sandstone that the well near the coal chute was drilled into in 1903, and bad boiler water secured.
Cambrian	990 to 1000	Light yellow dolomite
	1000 to 1009	Blue slate—8″ shoe 1008 feet—dry hole
	1009 to 1039	Very fine buff sandstone
	1039 to 1041	Coarser sandstone—water bearing
	1041 to 1108	Buff and light brown Dolomite, highly arenaceous.
	1108 to 1205	Light brown Dolomite, somewhat arenaceous.
	1205 to 1240	Light buff dolomite, highly arenaceous.
	1240 to 1318	Light buff dolomite, somewhat arenaceous.
	1318 to 1408	Light buff dolomite, highly arenaceous.
	1408 to 1494	Light buff dolomite, somewhat arenaceous.
	1494 to 1515	Light gray dolomite
	1515 to 1535	Light gray dolomite
	1518	Cased with 6″ and made a dry hole
	1535 to 1572	White sand, struck water which rose to 130 feet below surface (Roubidoux?)
	1572 to 1582	Shale
	1582 to 1584	Limestone
	1584 to 1590	White sand
	1590 to 1642	Limestone
	1642 to 1646	Hard sand rock
	1646 to 1666	Limestone
	1666 to 1668	Sand rock
	1668 to 1669	Gray limestone
	1669 to 1694	Limestone
	1694 to 1770	White sand rock
	1770 to 1773	Gray sand, water bearing
	1773 to 1782	Limestone—no water
	1782 to 1793	Hard sand rock
	1793 to 1810	Sand rock
	1810 to 1842	Gray limestone
	1842 to 1897	White limestone
	1897 to 1912	Blue limestone
	1912 to 1964	Gray limestone
	1964 to 1999	Blue limestone
	1999 to 2028	Gray limestone
	2028 to 2053	Blue limestone
	2053 to 2058	Blue limestone
	2058 to 2102	Gray limestone
	2102 to 2125	Blue limestone
	2125	Quit drilling and abandoned well, 1317 feet below sea level.

inches, the water rises within 125 feet of the surface, and about 15 gallons per minute are pumped. The supply is salty.

LEWIS COUNTY

On the grounds of the Christian University at Canton, the city drilled a well for fire protection. It is 900 feet deep; 6 inch casing to 100 feet; flow 72 gallons per minute. A strong flow of water was struck in the St. Peters sandstone at 870 feet below the surface. The water is used for nearly all domestic purposes but it has a slight sulphur odor, and possesses mild laxative qualities. The Aqua Vitae Mineral Springs Company sub-leased the right to ship water for medicinal purposes.

At LaGrange there are three flowing wells. One was originally owned by the LaGrange Mineral Well Prospecting Company. Later the two oldest wells came under the same ownership, and their products sold as the "Wyaconda Water."

The depth of these wells is 800 and 850 feet but only imperfect records were kept of the drilling. The main flow of water was reached at about 800 feet in the St. Peters sandstone. The flow varies from 40 to 60 gallons per minute and is excellent water.

In June 1913 Mr. W. W. Heald finished an 850 foot well at LaGrange. Abundance of fresh water was reached at a depth of 200 feet, but flowing water began at the 800 foot level. The drilling was continued until a depth of 850 feet was reached. The diameter of the well is 6 inches, and the water flows from the mouth with a 40 pound pressure. The quality of the water seems similar to that of the previous wells at LaGrange. The following is a log determined from the samples obtained.

Log of LaGrange (1913) Well.

	Depth in feet	Character of Rock
Pleistocene	20	Clay and soil
Mississippian	93	Limestone and flint
	165	Shale and limestone
	185	Brown limestone
	210	Pink limestone
Probable Devonian	360	Shale and thin limestone
Silurian and Ordovician	518	Limestone
	520	Chert and limestone
	534	Limestone
	542	Limestone with sand bearing small lead cubes
	743	Chert with limestone
	850	Limestone and fine sand

LINCOLN COUNTY

A well owned by G. S. Brown at Ethlyn is 187 feet deep, 6 inches in diameter; principal source 185 feet and water rises within 52 feet of the surface.

Near Troy there is a well owned by N. Hanni which is 136 feet deep. This well flows about 1 gallon per minute. No logs were kept of these wells, but their water probably comes from the lower Mississippian or Devonian rocks.

MARION COUNTY

In Marion County there are a number of flowing and non-flowing wells. The principal source of supply is from the St. Peters sandstone which is reached from 600 to 800 feet below the surface. The water although containing salt and sulphur is generally used for domestic purposes.

The following log of the Vernet well at Hannibal was obtained from Mr. R. Hawkins of Chillicothe:

Log of Vernet Well, Hannibal, Mo.

	Depth in feet	Thickness of Strata feet	Character of Rock. Remarks.
Pleistocene	0 to 41	41	Soil and clay
Mississippian	41 to 195	154	Shales and limestones
	195 to 300	105	Blue limestone
Devonian	300 to 333	33	Black slate
	333 to 347	14	Salt water sand
Silurian and Ordovician	347 to 601	254	Limestone
	601 to 697	96	Mineral water sand: St. Peters; water rose within 40 feet of the surface.
Cambrian	697 to 950	253	Limestone, hard; fine sand at intervals; water rose to 20 feet from surface.
	950 to 1000	50	Hard limestone
	1000 to 1005	5	Soft, white sand (Roubidoux)
	1005 to 1055	50	Limestone
	1055 to 1205	150	Limestone and interstratified sand
	1205 to 1225	20	Sand
	1225 to 1275	50	Magnesian limestone
	1275 to 1285	10	Hard, white sand; water within four feet of surface.
	1285 to 1389	104	Magnesian limestone; water flowing.
	1389 to 1435	46	Unaccounted for

MONROE COUNTY

The Monroe County Poor Farm has a deep well 2½ miles southeast of Paris. It is 5½ inches in diameter and the depth is 430 feet. The water rises to within 90 feet of the surface. The principal water comes from 420 feet below the surface and is probably from the St. Peters sandstone.

Wells in Marion County, Missouri.

Location	Owner	Contractor	Driller	Depth in Feet	Diam. in Inches	Depth to Principal water. Feet.	Yield in gallons per minute		Elevation above sea level. Feet.		Remarks
							Flow	Pump	Water level	Well Site	
Hannibal	Mrs. Vernet			1435	6	1005			575	608	Salt water
Hannibal	Richard Stillwell Meat and Ice Co.			950	8	800	208		500	475	50 lbs. pressure, saline .
3 miles S. of Nelsonville	C. H. Mohr		C. H. Mohr	720	4 1-2	685	1 1-4				
3 miles S. of Nelsonville	C. H. Mohr		C. H. Mohr	875	4 1-2	600	10				Water rises in pipe 12 ft. above surface
3 3-4 miles N. W. of Monroe City	W. R. Jackson		C. S. Jackson	700	6						Incomplete report
Palmyra				1683		700					Flowed

In the spring of 1913 Monroe County attempted to install a deep well for city supply, but the project was unsuccessful. A well was bored 2150 feet, and cased about 1600 feet. Only salt water was obtained from this well, although definite information about the water at various horizons was not saved. The salt water was struck about 500 feet below the surface in the probable St. Peters sandstone, and another flow which seemed fresh at first and later became salty, was encountered at 1000 or 1100 feet. This water might have proved fresh, had the salt water been properly cased off from above. The city was under considerable expense for the drilling, and consequently abandoned the proposition.

MONTGOMERY COUNTY

Numerous wells are known in Montgomery County, varying in depth from 100 to 250 feet. These wells furnish good water for stock and farm uses. No record of any has been kept.

PIKE COUNTY

At Louisiana, Missouri, the old "Thespian Spring" is famous as an artesian well. It is 1275 feet deep and 6 inches in diameter. The principal source of supply is about 600 feet below the surface in the St. Peters sandstone as stated by Dr. Shepard.* The water bubbles up with about an eight foot head, and is strongly charged with salt and sulphur. At present the water is not used extensively for drinking purposes.

RALLS COUNTY

The St. Peters sandstone is penetrated by most of the wells in Ralls County from 250 to 400 feet below the surface. The sandstone is reported to outcrop in the extreme eastern part of the county, and most of the wells are situated in the western and southwestern parts. The water obtained in some cases is soft while in others it contains sodium and magnesium salts.

RANDOLPH COUNTY

This county is about on the dividing line, between the St. Peters and Roubidoux provinces, being the westernmost county showing St. Peters sandstone. A number of wells have been drilled in the county, but records of only a few have been obtained. The Wabash Railroad drilled 642 feet at Moberly in 1901 and reached St. Peters sandstone at 629 feet from the surface. A good, comparatively soft water was obtained at this horizon.

*U. S. Geological Survey Water Supply Paper No. 195, p. 52.

Log of Wabash R. R. Co. Well, Moberly, Mo.

Drilled in 1901.

	Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
Pleistocene	0 to 78	78	Drift
Pennsylvanian	78 to 84	6	White limestone
	84 to 88	4	Clay (caving)
	88 to 218	130	Sandstone, some water in top.
	218 to 236	18	Fire clay
Mississippian	236 to 281	45	Gray limestone
	281 to 291	10	Brown shale or slate
	291 to 298	7	Sand stone, a little water.
	298 to 310	12	Clay, caving
	310 to 335	25	Blue and white limestone
	335 to 340	5	Soapstone
	340 to 400	60	Dry, hard, sandstone.
	400 to 545	145	Blue limestone (hard and soft)
Devonian and Joachim	545 to 553	8	Dark brown shale
	553 to 556	3	Water sand
	556 to 568	12	Blue shale
	568 to 613	45	Trenton rock
	613 to 629	14	White, soft limestone.
St. Peters	629 to 642	15	Sandstone (St. Peters?)

The city water plant at Moberly pumps two eight inch wells. The depths of these are 500 and 510 feet respectively. About 150,000 to 200,000 gallons can be pumped from each well per day at a maximum, but both cannot be run on full load at the same time. The water obtained is very satisfactory for domestic purposes.

Some years ago a 2000 foot well was drilled at Moberly, and excellent water obtained at 632 feet. At 870 feet the water became salt and from there on was impregnated with salt and sulphur. The record of this well is in U. S. Geological Survey Water Supply Paper, No. 195, p. 102.

In the record Dr. Shepard has correllated the sand at 1105 feet as the St. Peters sandstone. In this work that sand has been called the Roubidoux and the sandstone at 632 feet called the St. Peters. The reasons for this change are as follows:—In Dr. Shepard's correllation he has shown 95 feet of Niagarian, 234 feet of the Hudson group, and 131 feet of Trenton rock. These aggregate 450 feet of materials above the 1100 foot sandstone that do not outcrop anywhere south along the Missouri River in Howard, Boone and Callaway Counties. As stated in the chapter on conditions of the Northeastern Province, the St. Peters sandstone pinches out in southern Callaway and Boone Counties and is found only in isolated patches, occupying synclines directly below the Joachim, and never more than 100 feet below the Mississippian. No Trenton, Niagarian or Hudson rocks are known to outcrop in Missouri west of a thin pinching section in the northeastern part of Callaway County. Moreover a deep well at Centralia strikes the Roubidoux sandstone at 1085 feet below the surface. A deep well at Marceline strikes a similar sandstone at 1104 feet. These two localities are about equally distant on either side of Moberly. In the Centralia well a water bearing sandstone was encountered at 534 feet and this has been supposed to be a thin edge of the St. Peters as it is not shown in the Columbia wells farther south.

A number of wells in Randolph County obtain a good supply of water at about 600 feet, evidently from the so-called St. Peters horizon. The water rises to within about 75 feet of the surface and is of excellent quality but the Robidoux water 400 feet below seems to be highly mineralized (due to local underground conditions) and can not be used for domestic purposes.

SCOTLAND COUNTY

Near Rutledge there have been several wells drilled for farm purposes. These vary in depth from 300 to 500 feet but do not strike the St. Peters sandstone. The water is hard and probably comes from the lower Mississippian or upper Devonian rocks.

WARREN COUNTY

At Warrenton there is a well which strikes the St. Peters sandstone at 360 feet below the surface. It is 400 feet deep and is 6 inches in diameter. There are several wells at Wright City varying from 100 to 250 feet deep. These furnish a good supply of hard water but it is not thought to come from the St. Peters sandstone. It is safe to assume that a good quantity of water may be expected throughout the northern half of Warren and Montgomery counties within 400 feet of the surface.

ST. LOUIS AND ST. LOUIS COUNTY

The rocks in the St. Louis region lie in a peculiar trough. The surface formation is the Upper Coal Measures, and sections show a great increase in thickness of underlying strata. At the corner of Main and O'Fallon streets, St. Louis, a well known as the Belcher well was finished in 1854. The depth of this well is 2199 feet; elevation 420 feet; and it flows about 75 gallons per minute. A detailed description of this historic well may be found in "Transactions St. Louis Academy of Science," Vol. I, 1860, pp. 82 to 86.

In 1869 a deep well was completed at the St. Louis Insane Asylum. The log of this well was furnished by the late Prof. G. C. Broadhead, who published the same in the Transactions of the St. Louis Academy of Science, Vol. 3, No. 2, 1878, p. 216. The elevation of the well site is about 600 feet; the St. Peters sandstone was struck at 1452 feet and furnished an abundant supply of sulphurous water.

A number of wells have been drilled in St. Louis County varying in depth from 100 to 1500 feet. In all drillings to 1400 or 1500 feet a rather salty water is obtained from the St. Peters sandstone. Shallower wells furnish water, but not in great quantity. The water from the deeper wells rises to within 100 feet of the surface and a few wells are flowing.

Log of Insane Asylum Well, St. Louis.—Broadhead.

	Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
Pennsylvanian	0 to 40	40	Clay
	40 to 44	4	Limestone, not in place.
	44 to 49	5	Red clay
	49 to 57	8	Limestone
	57 to 61	4	Red clay
	61 to 66	5	Coal
	66 to 68	2	Fire clay
	68 to 71	3	Light colored limestone (begin boring)
	71 to 80	9	Blue and drab clay, slightly calcareous.
	80 to 86	6	Cherty limestone
	86 to 107	21	Dark and bluish grey shales, slightly calcareous
	107 to 111	4	Cherty limestone
	111 to 112	1	Coal
	112 to 120	8	Light blue clay
Mississippian	120 to 259	139	Hard cherty limestone, blue, drab and grey, upper part fine and lower course ground.
	259 to 262	3	Blue shales
	262 to 438	176	Drab and grey limestone
	438 to 500	62	Dark drab limestone
	500 to 536	36	White limestone and shale (record)
	536 to 628	92	Hard, blue cherty limestone.
	628	....	Very hard chert
	628 to 763	75	Coarse, bluish grey limestone.
	703 to 709	6	Sandstone, very fine grained.
	709 to 790	79	Light grey or drab limestone, cherty.
	790 to 800	10	Red limestone
	800 to 835	35	Light drab and grey limestone, some chert.
	835 to 840	5	Argillaceous limestone
	840 to 883	43	Limestone with some chert, light grey.
Devonian Silurian and Ordovician	883 to 950	67	Light blue or blue clay
	950 to 966	16	Dark clay
	966 to 1022	56	Blue clay, alternating with thin limestone layers.
	1022 to 1216	194	Blue and drab limestone, probably some magnesian layers at 1139 feet.
	1216	....	Colored magnesian limestone
	1216 to 1225	9	Light blue cherty limestone, salt water at 1220 feet.
	1225 to 1252	27	Light colored limestone
	1252 to 1304	52	Dark limestone
	1304 to 1353	49	Light drab, cherty limestone.
	1353 to 1370	17	Yellowish grey limestone
	1370 to 1448	78	Dark colored limestone
	1448 to 1452	4	Light colored limestone
	1452 to 1583	31	White rounded grains quartz sand containing sulphurous water; (St. Peters)
Cambrian	1583 to 1646	63	Buff, brown and drab cherty limestone.
	1646 to 1713	67	Buff, brown, magnesian limestone.
	1713 to 2102	389	Buff, drab, cherty magnesian limestone.
	2102 to 2184	82	Hard and mostly pure sandstone, some limestone and chert, buff, brown, reddish, grey; (Roubidoux)
	2184 to 2671	487	Limestone and chert, beds of chert about one half.

Log of Insane Asylum Well, St. Louis—Continued.

	Depth in feet	Thickness of strata feet.	Character of Rock. Remarks.
Cambrian	2671 to 2735	64	Limestone, no chert, sand.
	2735 to 2843	108	Limestone and sand
	2843 to 2880	37	Sandstone, some limestone.
	2880 to 3022	142	Limestone, mainly free from chert and sand.
	3022 to 3120	98	Sandstone, upper part cherty, middle blue, lower reddish grey
	3120 to 3133	13	Dark magnesian slate.
	3133 to 3504	371	Yellowish drab or grey magnesian limestone, hard, little sand; lower part thin, bedded with sand.
	3504 to 3545	41	Thin bedded hard sandstone, olive grey color
	3545 to 3558	13	Sand and limestone.
	3558 to 3843	285	Brown sandstone in upper part, lower 40 ft. powdered granite.

CHAPTER III.

CONDITIONS IN THE CENTRAL AND SOUTHWESTERN DISTRICT

This province includes the area underlain by the Roubidoux sandstone. The artesian conditions vary uniformly throughout the district, and good results from deep wells are much more general in this area than in northeastern Missouri. The rocks dip mostly to the north in the central counties and to the west in the southwestern ones; the counties on the inner border having the most favorable location. Flowing wells are not common in the province, although the best conditions for flowing wells in the state are probably found at Clinton. Flowing wells are reported from Newton, McDonald and Saline counties.

The quantity of water is sufficient in all localities where it can be pumped economically. The quality varies with local conditions, sometimes being impregnated with salt and sulphur, but not generally so burdened with mineral matter as to be objectionable for domestic uses. In Howard, Saline, Lafayette, Chariton and Linn counties the Roubidoux formation furnishes a strong salt water. It is the general belief of the writer that fresh water can be obtained in these localities from the Gasconade sandstone 300 to 400 feet below the Roubidoux as was illustrated in one of the Higginsville wells but this can only be substantiated or disproved by actual experiment.

BOONE COUNTY

Boone County is underlain by the Roubidoux formation and a number of wells yield an excellent supply of water from this horizon. The sandstone may be reached at about 400 or 500 feet below the surface in the extreme southern part of the county and varying from there to 900 or 1000 feet along the northern boundary.

The following is a log of the University well which was very carefully kept and worked out. This may be taken as an average Boone County section.

Log of University of Missouri Well No. 2, Columbia, Mo.

The well is located 25 feet south of the Engineering Annex Building on the campus of the University. Surface elevation, 740 feet.

	Depth in feet	Thickness of Main formations in feet	Thickness of strata in feet	Character of Rock
	0 to 35	35	....	Mantle rock, part fill
Mississippian	35 to 200	165	....	Burlington limestone
	200 to 260	60	....	Chouteau limestone
Devonian	260 to 261	1	....	Sandstone
	261 to 301	40	....	Limestone

Log of University of Missouri Well No. 2, Columbia—Continued

		Depth in feet	Thickness of main formations in feet	Thickness of strata in feet	Character of Rock	
Cambrian	Jefferson City	301 to 680	379	79	Limestone	Limestone (Magnesian and generally cherty)
				5	Sandy limestone	
				123	Limestone	
				2	Fine grained sandstone	
				10	Light colored calcareous shale	
				5	Dark shale	
				7	Limestone	
				8	Sandstone, fine to coarse grained.	
				30	Limestone	
				5	Sandstone, fine grained, white.	
				20	Limestone	
				2	Sandstone	
				11	Limestone	
				7	Sandstone	
				49	Limestone	
				1	Sandstone	
				15	Limestone	
	Roubidoux	680 to 770	90	12	Fine grained sandstone	([illegible] sandstone)
				23	Limestone	
				41	Sandstone, fine grained, well rounded	
				3	Limestone	
				11	Sandstone to bottom of well	

CALLAWAY COUNTY

The conditions in Callaway County are similar to those of Boone County. Excellent water from the Roubidoux formation is obtained by a number of wells in Fulton and elsewhere. The depth of sandstone below the surface varies from about 400 to 900 feet from southern to northern extremities respectively. Logs of the Fulton wells are about the same as the Columbia well logs.

Wells in Boone County, Missouri.

Location	Owner	Contractor	Driller	Depth in Feet	Diameter in Inches	Depth of principal water	Yield in gallons per minute		Elevation above sea level		Remarks
							Flow	Pumped	Water level	Well Site	
Columbia	University	W. R. Nifong	W. R. Nifong	967	10-6	750-900			616	736	Steam pump
Columbia	University	O. G. Wilson		792	15 1-4-8	750-792		250	660	740	Electric motor-driven pump
Columbia	Christian College	W. R. Nifong	W. R. Nifong	676	5 5-8	525			630	750	
Columbia	Hetzler Bros' Ice Plant			617		500					
Columbia	Hetzler Bros' Ice Plant			640		500					
Columbia	Hamilton-Brown Shoe Co.			957	6 1 4	700-900		80	615	765	
Columbia	City of Columbia	P. L. Crossman		801	15-10	780		259			City water supply. Elec. motor driven pump
Columbia	City of Columbia	P. L. Crossman		848	15-10	780-814		259	603	795	City water supply. Electric motor driven pump
Centralia	City of Centralia	O. G. Wilson		1118	12-8	1085		200		885	City water supply
Centralia	City Development			1850	6 1-4	850-1000				885	Stopped, soft spot in slate demanded more casing
Columbia	City water works				10-6			150			City supply, air lift pumps
Columbia	City water works				10-6			150			City supply, air life pumps

Wells in Callaway County.

Location	Owner	Contractor	Driller	Depth in Feet	Diam. in Inches	Depth to principal water	Yield in gallons per minute		Elevation above sea level		Remarks
							Flow	Pumped	Water level	Well Site	
Fulton	City of Fulton	C. A. Wise	Jack Farro	1121	9	700-1000		250	670	820	Sandstone and limestone. City supply
Fulton	City of Fulton			800	8	800			670	820	City supply
Fulton	Deaf and Dumb School		Simmons	700	6			60	680	820	School supply
Fulton	State Hospital			1100	6	700-1000		72	670	820	Water very hard Use lime softener
Fulton	State Hospital			950	10	700-950		95	670	820	Water very hard Use lime softener
Fulton	State Hospital	Edwards, Diemer & Donner	W. M. Edwards	1000	12	700-100		350	670	820	Drilled fall of 1912
½ mile S. W. of McCredie	Crawford			115	7	115				860	Soft water
½ mile S. E. of McCredie	Harrison			130	7	130				850	Soft water
7½ mi. N. E. of Cedar City	George Carlton			1300							Water flows. Drilled for oil but none found
Cedar City	F. M. Pease & Co. Chicago	Chas. York	Chas. York	1282	10	800-1200				560	Stopped on account of excessive water pressure. Flows.

CALDWELL COUNTY

On the Robert Davis farm, 3 miles northwest of Braymer, the N. M. Murrey and Lecredopmut Co., drilled a well 1410 feet deep. The record of this well was carefully kept, although no report on the character of the water from the Roubidoux sandstone was obtained. Caldwell County is on the outer border of the Roubidoux province (that is, north or west of this county it would not be economical to drill to the Roubidoux sandstone for water). Good water seems to be furnished by wells ranging in depth from 150 to 300 feet, but below this depth the quality of the water is questionable. The following log of the Braymer well was furnished by Mr. R. Hawkins of Chillicothe,

Log of Braymer Oil Well, 3 Miles N. W. of Braymer, Mo.

N. M. Murrey and Lecredopmut Co.

	Depth in feet	Thickness of strata. feet	Character of Rock.	Remarks
Pleistocene	0 to 14	14	Clay	
	14 to 19	5	Limestone	
	19 to 20	1	Sandstone	
	20 to 24½	4½	Limestone	
	24½ to 34	9½	Sandstone	
	34 to 42	8	Oil shale	
	42 to 44	2	Soapstone	
	44 to 56	12	Shale	
	56 to 62	6	Limestone	
	62 to 68	6	Slate and sand	
	68 to 76	8	Oil sand	
	76 to 81	5	Sand and slate	
	81 to 87	6	Soapstone	
	87 to 90	3	Sand and slate	
	90 to 95	5	Soapstone	
	95 to 99	4	Oil sand	
	99 to 135	36	Soapstone	
	135 to 143	8	Keel	
	143 to 155	12	Soapstone	
	155 to 171	16	Keel	
Pennsylvanian	171 to 179	8	Limestone	
	179 to 190	11	Soapstone	
	190 to 193	3	Hard limestone	
	193 to 198	5	(No record)	
	198 to 210	12	Limestone	
	210 to 228	18	Sandstone	
	228 to 235	7	Sand	
	235 to 237	2	Limestone	
	237 to 242	5	Slate	
	242 to 243	1	Soapstone	
	243 to 244	1	Limestone	
	244 to 246	2	Keel	
	246 to 251	5	Limestone	
	251 to 264	13	Soapstone	
	264 to 266	2	Keel	
	266 to 270	4	Soapstone	
	270 to 274	4	Hard limestone	
	274 to 301	27	Soft limestone	
	301 to 311	10	Soapstone	
	311 to 325	14	Shale	
	325 to 330	5	Soapstone	
	330 to 345	15	Limestone	

Log of Braymer Oil Well—Continued.

	Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
	345 to 350	5	Soapstone
	350 to 351	1	Hard flint
	351 to 353	2	Slate
	353 to 354	1	Hard flint
	354 to 375	21	Limestone
	375 to 377	2	Soapstone
	377 to 382	5	Sand shale
	382 to 383	1	Limestone
	383 to 394	11	Soapstone
	394 to 395	1	Limestone
	395 to 396	1	Coal
	396 to 399	3	Soapstone
	399 to 410	11	Dark clay
	410 to 420	10	Soft limestone
	420 to 431	11	Soapstone
	431 to 433	2	Limestone
	433 to 434	1	Coal
	434 to 437	3	Slate
	437 to 441	4	Limestone
Pennsylvanian	441 to 462	21	Shale
	462 to 470	8	Clay
	470 to 473	3	Limestone
	473 to 501	28	Dark shale
	501 to 507	6	Soft limestone
	507 to 517	10	Dark shale
	517 to 518	1	Flint
	518 to 524	6	Slate
	524 to 528	4	Iron shale
	528 to 534	6	Limestone
	534 to 543	9	Soapstone
	543 to 544	1	Limestone
	544 to 563	19	Soapstone
	563 to 569	6	Limestone
	569 to 599	30	Dark shale
	599 to 672	30	Saline sand
	632 to 634	2	Soapstone
	634 to 652	18	Sandstone
	652 to 660	8	Grayish dark clay
	660 to 664	4	Clay
	664 to 666	2	Hard sandstone
	666 to 673	7	Hard sand
	673 to 767	94	Limestone
Mississippian	767 to 770	3	Salt water
	770 to 797	27	Limestone
	797 to 798	1	Blue shale
	798 to 886	88	Limestone
Devonian and probable Ordovician	[illegible]6 to 916	30	Slate
	916 to 941	25	Limestone
	941 to 1285	344	Unrecorded
	1285 to 1290	5	Brown limestone and grit
	1290 to 1358	68	White sand (Roubidoux sand)
Cambrian	1358 to 1363	5	Black shale
	1363 to 1375	12	Flint and limestone
	1375 to 1392	17	White shale
	1392 to 1410	18	Gray limestone

CARROLL COUNTY

Five miles southeast of Braymer there is a well on the Winterroad Farm. A good flow of fresh water was found about 150 feet below the surface, but salt water came in at the 500 foot level. This well was drilled about 1100 feet and the exact record could not be obtained. Other records from Carroll County do not reach the Roubidoux formation and consequently are of little value in this report. The general conditions are similar to those of southeastern Caldwell County. Fresh water was struck within about 150 or 200 feet of the surface, and from 300 to 500 feet salt water entered the wells. The Roubidoux sandstone probably underlies the county within 1000 or 1200 feet of the surface, but no definite idea of the quality of the water below that level has been obtained.

CHARITON COUNTY

In 1887 a well was sunk 1 mile north of Brunswick for the purpose of striking oil. The depth of this well was 1505 feet and the surface elevation was 712 feet above sea level. At about 300 feet strong salt water was encountered. At a depth of 1400 feet water began to flow, but has ceased since that date and the water now stands within 10 feet of the surface. It is strongly charged with salt and sulphur. The source of this water is probably from the Gasconade sandstone, as the Mississippian limestone was reached 130 feet from the surface.

The city of Salisbury drilled an 852 foot well in 1896. At 150 feet and 210 feet, fresh water was obtained but below 600 feet a strong flow of salt water was struck. Other well records have been reported, but the general conditions seem to indicate that in local coal measure lenses fresh water may be obtained within 200 feet of the surface, and that the deeper waters are too strongly impregnated with salt for domestic use.

COOPER COUNTY

Although in a most favorable location, Cooper County has no wells reported as reaching the Roubidoux sandstone. This sandstone underlies the whole county, ranging from 400 to 900 feet below the surface, and doubtless would furnish excellent water.

GREENE COUNTY

Several deep wells in Greene County obtain excellent water from the Roubidoux formation. The St. Peters sandstone is reached at about 400 feet below the surface and furnishes good water. The Roubidoux sandstone increases the supply at 600 feet. As high as 750 gallons per hour have been pumped without lowering the water level in the well at the Car Shops at Springfield. These wells have been carefully studied by Prof. E. M. Shepard and the following log is copied from his report in U. S. Geological Survey Water Supply Paper No. 195, p. 133.

Log of Well at Car Shops, Springfield, Mo.

		Depth in feet	Thickness of strata in feet	Character of Rock
Mississippian	Burlington	0 to 35	35	Soil and limestone
		35 to 153	118	Gray limestone
		153 to 215	62	Flint and limestone
		215 to 250	35	Limestone
	Chouteau	250 to 280	30	Soft slate or soapstone
		280 to 297	17	Gray limestone
Devonian		297 to 301	4	Light gray sandstone (Phelps sandstone)
		301 to 318	17	Light gray limestone
		318 to 330	12	Flint, limestone and pyrites
		330 to 336	6	Light gray limestone (King limestone)
Ordovician	Joachim	336 to 340	4	Flint and limestone
		340 to 347	7	Gray limestone
		347 to 372	25	White gritty limestone
		372 to 375	3	Fine limestone
		375 to 390	15	Coarse limestone
	St. Peters?	390 to 398	8	Porous sandstone
		398 to 406	8	Limestone and some sand
Cambrian	Jefferson City	406 to 435	29	Bluish brown limestone
		435 to 512	77	Fine flinty limestone
		512 to 522	10	Fine sand
		522 to 532	10	Fine gray limestone
	Roubidoux	532 to 587	55	Very fine sand rock
	Gasconade	587 to 592	5	Brown limestone
		592 to 600	8	Flinty siliceous rock
		600 to 610	10	Very fine white sand rock
		610 to 620	10	Finer sand
		620 to 645	25	Sand
		645 to 678	33	Brownish gray limestone and flint
		678 to 690	12	Reddish brown limestone
		690 to 698	8	Gray limestone and white flint
		698 to 720	22	Fine white sand, sharp grit

HENRY COUNTY

Clinton has for a long time been famous for its artesian wells. In the city there are six wells, the first having been drilled in 1887. This well was owned by Mr. H. P. Faris and the cuttings were saved by Dr. J. H. Britts. A little over a million gallons flow from this well per day, the head rising in a pipe about 12 feet. The bore is 8 inches for the first 400 feet; 5½ from there to the bottom (850 feet)

An excellent supply is furnished the city from these wells although the water has a slight sulphur taste. At Hartwell a well has been drilled within the last two years for a hunting club lake. The depth is 1190 feet, and an abundant supply of good water was obtained.

The following is a log determined from the Clinton well cuttings which were presented to the University by Mrs. J. H. Britts of Clinton, Mo.:

Log of the Clinton Well.

		Depth in feet	Thickness sampled in feet	Character of Rock
Mississippian	Burlington	0 to 40	40	Clay and shaly blue pebbles, well rounded.
		40 to 50	10	White spongy chert, little lime.
		50 to 60	10	White chert, very little lime.
		60 to 70	10	White and blue chert
		70 to 80	10	Gray limestone, decidedly cherty.
		80 to 90	10	White lime, soft, very little chert.
		90 to 100	10	Darker gray lime, white lime and some shale.
		100 to 110	10	Soft gray shaly limestone
		110 to 120	10	Gray limestone, compact (with chert)
	Chouteau	120 to 130	10	White crystalline limestone, no chert.
		130 to 135	5	White crystalline limestone, no chert.
		135 to 160	25	Blue limestone, splintery, some chert.
		160 to 170	10	Blue shaly limestone, splintery.
		170 to 180	10	Blue limestone with little blue chert
		180 to 190	10	Shaly blue limestone with little chert
Devonian		190 to 200	10	Gray shaly limestone
		200 to 210	10	Blue cherty limestone, siliceous.
		210 to 220	10	Gray, white limestone, chert.
		220 to 230	10	Gray shaly limestone, some chert.
Ordovician	Joachim	230 to 240	10	White magnesian cotton rock, no chert.
		240 to 250	10	White magnesian cotton rock, no chert.
		250 to 260	10	White magnesian cotton rock, no chert.
		260 to 270	10	Bluish gray shaly magnesian limestone, slightly siliceous, cherty.
	Probable St. Peters	270 to 280	10	Shaly magnesian limestone with sand
		280 to 290	10	Calcareous, magnesian iron stained sand, about ½ sand, fairly fine.
		290 to 300	10	Same as above, more iron and more chert.
		300 to 310	10	Same, with a great deal of chert (first water)

Log of Clinton Well—Continued.

		Depth in feet	Thickness sampled in feet	Character of Rock.
Cambrian	Jefferson City	310 to 320	10	Sandy, iron stained, hard magnesian limestone, cherty.
		320 to 330	10	Iron stained, hard magnesian limestone, cherty.
		330 to 340	10	Spongy, gray, magnesian limestone, iron stained.
		349 to 350	10	Fine grained magnesian limestone
		350 to 360	10	Fine grained, sandy magnesian limestone.
		360 to 370	10	Same, with chert
		370 to 380	10	Iron stained, sandy, dolomitic limestone.
		380 to 390	10	Gray cherty, magnesian limestone.
		390 to 400	10	Dolomitic limestone
		400 to 500	100	Brown, sandy magnesian limestone with some chert.
	Roubidoux	500 to 525	25	Fairly well rounded pure quartz grains, about 2/3 sand and 1/3 magnesian limestone (water)
		525 to 670	145	Cuttings not taken on account of water pressure
	Probable Gasconade	670 to 700	30	Gray, silicieous, dolomite limestone.
		700 to 800	100	Gray, sandy limestone.
		800 to 850	50	Fine, white sand.

HOWARD COUNTY

Unfortunately this county seems to be underlain by a great salt basin and the waters from the deep formations are strongly impregnated with salt. In the Marshall well at Boon's Lick fresh water was reported to have come in at 1001 feet, but this has later been denied. In the Fayette well (860 feet deep) the water is also highly charged with salt. The salt springs in Howard and Saline counties very likely have their source in the lower formations as the spring water analyses are similar to those of the well waters. This water probably comes from the Roubidox and Jefferson City formations and whether or not the Gasconade formation will furnish fresh water can only be ascertained by drilling through this salt water level.

JASPER COUNTY

The conditions in Jasper County are excellent for deep wells. The Roubidox sandstone is reached from 900 to 1100 feet below the surface and furnishes abundant water. The city of Carthage has five wells varying in depths from 1000 to 1600 feet. The elevation of the well sites is about 730 feet above sea level, and the water rises within 100 feet of the surface. Since the wells have been worked, the supply seems to have increased. Only about 60 per cent of the total plant capacity has ever been used, and the water obtained is one of the best public supplies in the state.

Webb City also obtains its city water from deep wells. There are five wells ranging in depth from 857 to 1307 feet. The water rises within 200 feet of the surface; the elevation of the pumping station being 970 feet above sea level. About one and a half million gallons of excellent water are pumped per day.

The Carpenter and Schaffer well at Joplin did not obtain a sufficient flow from the sandstone at 1100 feet but drilled on to 1350 feet. Here a good supply was obtained from a porous magnesian limestone. The well has a diameter at the bottom of 8¼ inches; water rises to 115 feet from the surface, and drops to 140 feet when pumped. The maximum daily consumption is about 300,000 gallons. The water contains a magnesian compound which deposits a hard scale in the pipes.

Other wells throughout the county are similar to the Carthage and Webb City wells. The water comes both from sand lenses and porous limestones. It undoubtedly has its source of supply from the Roubidoux formation, and a good quality of water may be had in all parts of the county from this horizon.

JOHNSON COUNTY

No deep wells in this county are known to reach the Roubidoux formation which underlies the county at a depth of about 1100 feet and probably would furnish a good supply of water. Several wells obtain water from local coal measure lenses and from Devonian sandstones.

LAFAYETTE COUNTY

The Higginsville Prospecting Company in 1898 drilled a well in Higginsville. This well is 1512 feet deep with a diameter of 10 inches at the top, and 4½ inches at the bottom. It is cased all the way down. A strong flow of comparatively fresh water was struck at about 656 feet. At 1071 salt water rose within 80 feet of the surface. This water probably comes from the Roubidoux sandstone as in the wells in Carroll, Saline and Howard counties. Fresh water was again obtained at 1371 feet, probably from the Gasconade formation. The casing now leaks and the salt water seeping into the pipes destroys the value of the well.

The city of Higginsville has several wells for city supply, varying from 250 to 800 feet in depth. The last one, completed in April, 1913, is 732 feet deep; diameter 10 inches, and the water rises within 100 feet of the surface. The supply comes from a sandstone lens about 25 feet thick, and the water tastes of sulphur.

LINN COUNTY

The conditions in Linn County are similar to those of Livingston and the adjoining southern counties. Several shallow wells obtain fresh water from 100 to 200 feet below the surface. In Marceline the Roubidoux sandstone was struck at 1104 feet and furnished a large supply of salt water, which rose within 60 feet of the surface. The following log of the Marceline well was obtained from Mr. R. Hawkins of Chillicothe, Mo.

Log of Well at Marceline, Mo.

Elevation, 775 feet. Reported by G. W. Early, Oct. 17, 1907

		Depth in feet	Thickness of strata. feet	Character of Rock.
Des Moines		0 to 20	20	Surface
		20 to 25	5	Sandstone
		25 to 27	2	Clay
		27 to 32	5	Sand
		32 to 50	18	White shale
		50 to 51	1	Coal
		51 to 53	2	Fire clay
		53 to 55	2	Lime
		55 to 57	2	Shale
		57 to 63	6	Sandstone
		63 to 70	7	Slate
		70 to 72	2	Hard lime
		72 to 128	56	Shale
		128 to 130	2	Soapstone
		130 to 140	10	Sandy shale
		140 to 150	10	White shale
		150 to 178	28	Black shale
		178 to 183	5	Sandy shale (gas)
		183 to 233	50	Shale, dark
		233 to 273	40	Limestone
		273 to 283	10	Shelly lime and sand
		283 to 375	92	Lime and flint
		375 to 380	5	White sand
Mississippian		380 to 545	165	Lime flinty
		545 to 547	2	Green shale
		547 to 592	45	Lime
		592 to 594	2	Green shale
		594 to 701	107	Lime—Mississippian
Devonian and Joachim		701 to 704	3	Green shale
		704 to 724	20	Lime
		724 to 729	5	Green shale
		729 to 799	70	Lime, same as above
		799 to 804	5	Green shale
Cambrian	Jefferson City	804 to 850	46	Lime—hard, flinty
		850 to 852	2	Green shale
		852 to 949	97	Lime, same as above
	Roubidoux	949 to 1104	155	White sand (Roubidoux)
		1104 to 2004	900	Lime and sand—same as above

Note: Salt water rose to within 90 feet of the top.

LIVINGSTON COUNTY

There are several deep wells in Livingston County, but most of them obtain water from the coal measure lenses at about the 200 foot level. The Roubidoux sandstone was struck at Chillicothe at 1100 feet below the surface. Three miles east of Chillicothe in the Adams well it was reached between 1000 and 1100 feet. The water in the Chillicothe well was fresh for the first few hundred feet; then became impregnated with sulphur and salt, and later became almost entirely salt and rose within 20 feet of the surface. The company desiring a boiler water could not afford to treat it so the hole was plugged at 134 feet. This vein contains considerable solid matter but has been used with good results. Unfortunately no analysis of the deep water could be obtained as the sample was lost in shipping after the hole had been plugged. In the Adams well the water rose within 75 feet of the surface and was strongly salt, as characteristic of the Roubidoux water in that locality. The following two logs of these wells were furnished by Mr. R. Hawkins of Chillicothe, Mo:

Log of Well at Municipal Electric Light Plant S. W. Corner of City of Chillicothe, August, 1911.

	Depth in feet	Thickness of strata. feet	Character of Rock. Remarks.
Des Moines	0 to 20	20	Yellow clay with much ground up limestone mixed through it.
	20 to 30	10	Yellow moulding sand
	30 to 124	94	Blue boulder clay with seam of black soft muck about 40 feet from top of it. Caved badly and cased with 13" casing.
	124 to 138	14	First foot sand, balance clean gravel with fresh water of apparent good quality, rose 75 ft.
	138 to 147	9	Gray shale
	147 to 151	4	Dark shale and slate; barren coal seam.
	151 to 244	93	Light shale
	244 to 248	4	Black muck; barren coal seam.
	248 to 256	8	Light shale
	256 to 263	7	Dark shale
	263 to 270	7	Gray shale
	270 to 274	4	Limestone
	274 to 301	27	Gray shale
	301 to 306	5	Hard sand
	306 to 321	15	Salt water sand; rose to 35 ft. of surface
	321 to 331	10	Black shale
	331 to 336	5	Fire clay
	336 to 360	24	Salt water sand; rose to 35 ft. of top
	360 to 364	4	Gravel salt water
	364 to 408	44	Shale—light and dark
Mississippian	408 to 565	157	Lime stone, white crystalline and a large portion white flint all the way through it.
	565 to 640	75	Gray limestone

Log of Well at Chillicothe—Continued.

		Depth in feet	Thickness of strata feet	Character of Rock Remarks.
Devonian and Joachim		640 to 650	10	Shale
		650 to 670	20	Limestone; dark
		670 to 710	40	Limestone, light and dark.
		710 to 820	110	White limestone; this was creamy white and looked like slacked lime when baled out—darker toward bottom.
		820 to 860	40	Dark brown limestone
		860 to 863	3	Sand
		863 to 873	10	Dark brown lime; very hard.
Cambrian	Jefferson City	873 to 935	62	Limestone Water at 883 (salt). This limestone was crystalline and porous and appears to be a magnesian lime very similar to the Trenton oil bearing rock at Anderson, Ind., from comparative tests with acid and also under magnifying galss.
		935 to 945	10	Hard limestone with much sand mixture.
		945 to 955	10	Hard sand
		955 to 961	6	Blue clay shale with boulders
		961 to 1040	79	Boulders embedded in blue clay—these boulders were white flint; gray limestone dark sand rock conglomerate with pebbles of different colors and character carried all the way from the top of clay down. After two days' rest, water rose to 35 feet of top of casing.
	Roubidoux	1040 to 1098	58	Crystalline magnesium limestone varying in fineness and in color every 5 or 6 ft. from gray to yellow and light brown—water bearing in at least part of it. Water rose to 20 ft. of top.
		1098 to 1145	47	Roubidoux sand Apparently a little oil in last limestone. The water had a coal oil smell in the upper part of it but this was thought at first to be caused by oil dropping from the casing. A thick yellow scum rising on the water was thought to be from rust on the casing. Lower down after repeated bailing, sand from the bottom on being washed impregnated the water so that a film arose showing plainly the characteristic peacock colors by reflected light. Oil trace.
		1145 to 1153	8	Dark blue, very plastic clay with black, slaty shale and hard, sandy shale or sand rock; caved badly; sand lower.
		1152 to 1194	41	Section 41 ft.
		1194 to 1205	11	Limestone, impure, sandy and very pyritic

Note: First casing 80 ft.; slipped 13 inches down about 30 ft.
Second casing, 10 inch to 150 ft.
Third casing, 8 inch to 408 ft.
Fourth casing, 6⅝ inch to 1040 ft.

Log of Well on Farm of C. E. Adam, Sec. 28, T. 58, R. 23.

	Depth in feet	Thickness of strata, feet	Character of Rock. Remarks.
Des Moines	0 to 30	30	Soft yellow clay
	30 to 45	15	Sand rock, yellow and rather soft.
	45 to 56	11	Light clay shale
	56 to 58	2	Hard conglomerate, different colors.
	58 to 61	3	Black shale
	61 to 130	69	Light colored gray shale
	130 to 132½	2½	Sand rock, 2 ft.; coal, 6 in.
	132½ to 190	57½	Light colored shale
	190 to 194	4	Black slate
	194 to 230	36	Light gray, clay shale.
	230 to 238	8	Variegated green and red clay shale; caved.
	238 to 251	13	Dark shale
	251 to 252	1	Limestone
	252 to 297½	45½	Gray clay shale
	297½ to 300	2½	Brown smut
	300 to 348	48	Drab to purple clays and shale of different colors with particles of coal.
	348 to 351	3	Soft, nearly white sand rock with mica particles in rounded grains like mustard seeds and larger.
	351 to 430	79	Black shale. Saline water began at 406 feet in this shale.
	430 to 442	12	Conglomerate mixture, not very hard, with iron pyrites; rather open texture, probably main source of saline water.
	442 to 452	10	Light bluish-white fire clay, very fat; but little sand.
	452 to 481	29	Same as last but darker and more sandy. Cased at 481 ft. with 5⅝-in. casing.
Mississipian	481 to 484	3	White limestone, very white and cherty.
	484 to 522	38	Limestone, white, with flinty layers. Also a layer of white, very soft, rock like gypsum, not affected by hydrochloric acid. Water rose, either from a thin loose stratum, or, more likely, broke through at bottom of last casing above; saline.
	522 to 584	62	Sand rock, flint, fire clay, thin slate; water worn, pebbly all about.
	584 to 596	12	Soft, chalky limestone.
	596 to 602	6	Flint, sand rock and black shale.
	602 to 616	14	Black shale
	616 to 636	20	Gray, soft sandy mixture.
	636 to 645	9	Flint, white sand, blue shale mixture.
	645 to 714	69	Gray, soft sandy mixture.
Devonian and Joachim	714 to 762	48	Darkish joint clay; caved all the way through it. Cased at 762 ft. with 4½-in. casing.
	762 to 766½	4½	White limestone
	766½ to 779	12½	Hydraulic, dark limestone.
	779 to 800	21	Soft white limestone
	800 to 846	46	Hydraulic limestone, dark mud rock.

Log of C. E. Adam Well—Continued.

		Depth in feet	Thickness of strata feet	Character of Rock. Remarks.
Cambrian	Jefferson City Formation	846 to 854	8	White flinty limestone
		854 to 881	27	"Bastard" limestone, dark colored. Water very soft at 861 ft., increasing in quantity probably down to 881 ft. Rose at first to 125 ft. from surface, afterward continued to rise till it reached 90 ft. from surface.
		881 to 906	25	Gray sandstone, fine and hard, with softer, whiter and coarser layers.
		906 to 917	11	Limestone
		917 to 982	65	Mixture, white flint, drab clay and sand rock, varying from fine to rather coarse. Some gas appeared when the bucket reached the top.
		982 to 990	8	Mixture, about 25% consisted of particles of black coal or fossilized organic matter which swelled like coal when burned wet; mashed easily into impalpable powder like lampblack. Remaining 75% rounded coarse sand of different colors, mostly opaque white.
	Roubidoux Formation	990 to 1065	75	Gray sand rock composed partly of white rounded grains of pure silica. Sample from top of stratum shows mixture of angular fragmentary sand and some of the black coaly material from the preceeding stratum. This stratum was soft in the lower part and slightly bluish in color; composed largely of "infusorial" sand. It caved badly and caused suspension of the work. Water was struck probably in the lower part; the exact point is unknown as the water already stood 90 ft. from the surface. The only indication was a rise in the water level to 75 ft. from the surface.
		1065 to 1066½	1½	Angular flinty sand with large mixture of metal flakes of steel color. Also mixed with round white silica sand (infusorial?)
		1066½ to 1076½	10	Same with lack of the metal and mostly flinty or like quartz.
		1076½ to 1101½	25	Pure white silica sand (infusorial?) rounded, nearly uniform in size and transparent like glass when magnified. Sand is fine, like fine cornmeal or granulated white sugar, with remarkable uniformity in size and shape of grains. Did not get through this last formation.

MORGAN COUNTY

Morgan County may receive water from both the Gasconade and Roubidoux formations. The Roubidoux sandstone underlies the northern part of the county varying from 200 to 400 feet below the surface, and out-crops along the streams near the southern boundary. The Gasconade formation lies about 250 or 300 feet below the Roubidoux and should furnish excellent water for this county. A few wells are known to penetrate the Roubidoux sandstone, and obtain a good supply of water although there is a tendency for the sand to clog the holes. This has been observed in the Moser Milling Company's well at Versailles. Small flowing wells are reported near Versailles; the average depth of these being about 200 feet.

NEWTON COUNTY

There are a number of wells in Newton County. Most of these are shallow, and some of them yield flowing water within 300 feet of the surface. At Neosho there is a well 1201 feet deep which flows 50 gallons of water per minute. The water is of an excellent quality containing only 230 parts of solids per million.

The data as to the strata penetrated was obtained from Dr. A. W. Benton of that city. After passing a few feet of clay in drilling, practically pure limestone continued to 275 or 300 feet. From there to 450 feet thin shale beds came in between limestone and flowing water was furnished from a 20 foot bed of shale at 450 feet. (This probably is a Devonian shale.) The water was impregnated with sulphuretted hydrogen; the flow being about 60 gallons per minute. From this level hard flinty limestone predominated, the shale disappearing and interbedded sandstones coming in. Two beds of pure sand were passed through, one at 900 and another between 1100 and 1200 feet. These formations have been classified as the Roubidoux and the Gasconade sandstones respectively. The quality of water gradually changed from the sulphur water of the shale to a fresh water in the lower sandstones.

Practically the same conditions should be expected throughout Newton County.

PETTIS COUNTY

The Sedalia City Water Works has for a long time obtained part of its water from deep wells. In the spring of 1913 arrangements were made to drill three or four new ones in order that the entire city supply might be from that source. These vary in depth from 400 to 600 feet. The Roubidoux sandstone carries excellent water at about 500 feet below the surface near Sedalia and a little deeper in the northern part of the county.

A deep well in Forest Park, about a mile north of the waterworks wells, was drilled in 1893. This well was 1612 feet deep, but only a partial log was kept and this does not furnish any definite idea of the strata.

SALINE COUNTY

The salt springs and wells in Saline County are believed to receive their water from the Roubidoux formation. The conditions here are similar to those of Howard, Chariton and Lafayette counties. A strong flowing well is located at Malta Bend. It is 1250 feet deep; elevation 690 feet above sea level; diameter 8¼ inches; flow 320 gallons per minute. The water in this well probably comes from both the Gasconade and Roubidoux formations. The Roubidoux sandstone was struck at about 900 feet but casing was only inserted 800 feet below the surface so the water below that level mingles freely, and it is not known whether or not the deeper water was fresh.

At Sweet Springs there is a flowing well, 1074 feet deep; elevation 670 feet; diameter 8 inches; flowing about 840 gallons per minute. Strong salt water came into the well at 604 feet below the surface. The Roubidoux formation carries the salt water but no efforts were made to investigate separately the water below that horizon.

VERNON COUNTY

Vernon County has several deep wells which furnish good water for domestic use. The Nevada Water Company supplies the city of Nevada from two wells 900 and 1000 feet deep respectively. The water comes from both sandsone and porous limestone, and stands within 65 feet of the surface. About 400,000 gallons are pumped per day. This water contains a scale forming compound which is very hard on the meters and water pipes, but otherwise is an excellent water for city supply.

Several flowing and non-flowing wells have been reported throughout this county and most of them are similar to the Nevada wells. The Roubidoux sandstone seems to be reached about 900 or 1000 feet below the surface and carries abundant water.

CHAPTER IV.

ARTESIAN PHENOMENA.

Water that rises in a tube is under pressure. Likewise water in an artesian basin is under a similar pressure and this force is called the artesian head. A water bearing stratum (covered by an impervious layer of material) dipping at a small angle is saturated with water from the outcrop or intake to the place where a well pierces the stratum. At the latter point the water is probably several hundred feet lower than the water at the intake, consequently (water seeking its own level) the difference in elevation is the cause of the water rising in the well. This difference in elevation in feet is the net artesian head, but the actual head working on the rising water is the net head minus all frictional resistances.

The measurement of this actual rise may be accomplished in one of two ways. If the water does not flow out at the surface, it is very convenient to measure the distance it comes from some mark on the surface and knowing the depth at which the drill struck the water formation the rise in the well is easily computed. Should the water flow out at the surface, this same method may be used by extending a pipe up from the drill hole until the water fails to flow out of the pipe, and this distance above the surface plus the depth to the water rock, is the head of rise in the well. However, in the case of flowing wells the last method is troublesome, and it is more convenient to attach a pressure gage to the water pipe. The pressure is read in pounds per square inch. Since a column of water 1 inch in cross-section, 2.3 feet high weighs 1 pound, the pressure reading multiplied by 2.3 equals the number of feet the water would rise above that point of pressure. This plus the depth to the water rock, is the artesian head.

The head of water rising in any well varies according to (1) elevation of the area of supply; (2) elevation of the surface of the well and depth at which water formation is struck; (3) hydraulic gradient due to frictional losses; (4) and in some cases to the age of the well.

Elevation of Supply Area.

It is manifest that to obtain pressure enough for an artesian basin 100 miles or more wide, it is necessary to have the intake well above any point in the basin. This is more forcibly understood when compared to a town water supply using a standpipe. The standpipe is usually placed on the highest point in the town, and built 100 feet or more high. By this gravity method 100 feet difference in elevation is required to force water through open pipes over a small area. Although in a reduced proportion (due to capillary attraction in the rocks) it is necessary to have a wide difference in elevation to force water with an economical head through rock over hundreds of square miles.

The Missouri field generally fulfills the requisites for a relatively high intake. The largest part of Missouri water is taken into the rocks on the flanks of the Ozarks where the elevation at the outcrop of the porous beds is between 800 and 1000 feet above sea level. As rocks dip away from the intake at about 20 feet to the mile, the elevation of the basin is just about that of sea level in 40 or 50 miles and below sea level beyond that distance from the intake.

Elevation of Well Site.

The water rising in a well in any locality rises from the water bearing stratum, and the higher the surface elevation above the water rock, the further from the surface will the water level stand, other factors remaining the same. When the surface elevation is equal or a little less than the elevation of the intake, a flowing well could not result owing to the frictional losses between the intake and well site. A flowing well can only be obtained where the intake is considerably above the well elevation, and the distance the water has traveled through the rocks not great enough to cause large losses.

As the depth to the water rock increases the height of water rising in the well decreases. This is on account of the increased friction in flowing through the rocks, due to the enormous pressure from the material above the water horizon. In preparing to drill a well it is economical to obtain the lowest convenient spot in order that the water bearing formations will be reached as soon as possible so that the water will rise nearer the surface.

Hydraulic Gradient and Frictional Losses.

The hydraulic gradient is a line which passes through the water level points in a series of wells proceeding away from the intake. It dips away from the intake showing that as the distance increases, the artesian head is diminished. This is not as important a factor as in the pipe line phenoména because of the slow movement of artesian water. Most of the openings in artesian sandstone according to Van Hise* are classed under capillary openings—that is, their maximum circular tubes are 0.508 mm. in diameter, and minimum 0.0012 mm. in diameter. Since the phenomena of artesian flow is partly capillary the friction is greatly diminished. Moreover friction varies with the velocity, so with artesian waters which move very slowly the friction is materially reduced. *"Apparently in the exceedingly slow movements of many of the larger masses of ground water the viscosity of water and the friction becomes almost zero per unit area. Evidence of this is furnished by the fact that artesian water flowing through rocks for hundreds of kilometers, the openings of which are capillary, may have nearly the full pressure due to head. For instance the artesian water adjacent to Lake Michigan at Chicago at the early wells, before they became so numerous as to interfere when allowed to flow, had a head 30 meters above the surface, and the feeding area is only about 80 meters above Chicago; yet the water has traveled under ground from 150 to 250 kilometers. The resistance causing the loss of head of 50 meters is to be distributed through this distance; therefore the friction per meter must have approached an infinitesimal amount. In such instances the average movement is exceedingly slow, for it will be shown that to accomplish the first of the above journeys more than a century was perhaps required."

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*Monograph 47, U. S. Geological Survey, p. 138.

Evidence from the Missouri wells shows that the flow of water is not altogether due to capillary attraction, because of the great loss in head; from 200 to 300 feet in 50 miles. Unfortunately the cuttings of the wells can not furnish data as to the size of the openings, but in many cases drill bits were noted to drop several inches through apparent cavities, showing that the water may often flow through larger openings.

Life of a Well.

It is of importance in engineering problems to know the approximate life of an artesian well. This seemingly simple piece of apparatus for obtaining water from the earth is similar to other machinery and is subject to repairs from time to time, and may finally become worn out.

A deep drill hole several hundred to a thousand feet passes through various kinds of rock material. Some are hard and brittle, others are soft and creeping under the enormous pressure of the rocks above. After the water has worked well aolng the sides of the drill hole these creeping layers thus lubricated, are liable to close in and not only fill up the hole but cause slips and cracks to form in the brittle rock above them. The water will wash away the chips of brittle fragments and finally leave cavities along the side of the hole. The solvent action of the water also helps to form these cavities and thus to shorten the life of the well.

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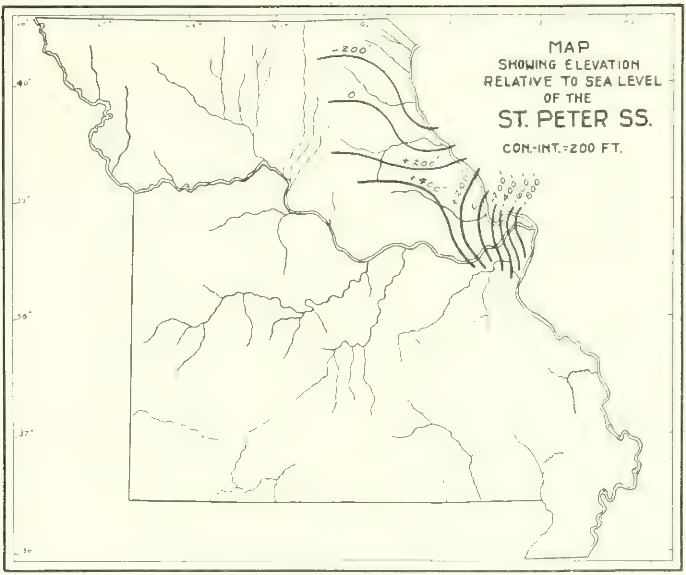
*Monograph 47, U. S. Geological Survey, p. 141.



In order to protect a well and to obtain best results in pumping water free from surface contamination, an iron casing is usually inserted at least part of the way down the deep hole. The care in the construction of this casing is one element that may eliminate future trouble.

It is often feared that a number of wells in a vicinity might over draw the supply of water and the yield of any one well would correspondingly drop. This is theoretically true, but no data as to the number necessary to reduce the flow in any locality has been obtained. At Carthage five wells are operated within a few hundred feet of each other, and no appreciable drop in the first well drilled has ever been noticed.

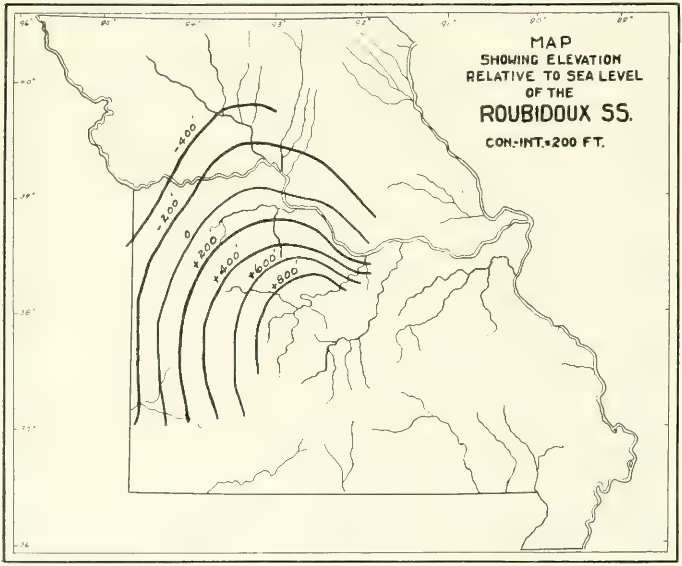
A well may last hundreds of years, depending upon the local conditions and the care with which it is operated.

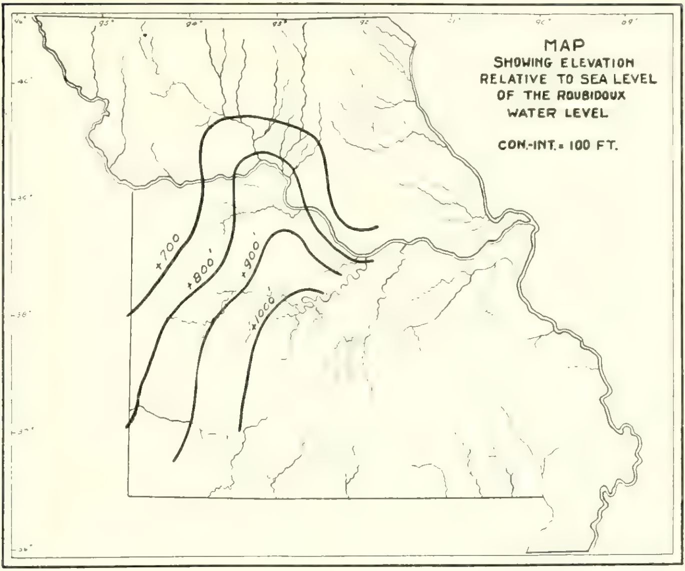
Artesian Phenomena of Missouri.

The principal water rocks of Missouri are the St. Peters sandstone, the Roubidoux and Gasconade formations. Each is most important in the area where it is the highest water stratum to furnish a sufficiently good supply. However these areas overlap each other and several water bearing beds may be penetrated in a single well. This is the case in north central Missouri where salt water is often obtained in local sandstone lenses as far down as the Ozarkian series and finally fresh water reached in the Roubidoux or Gasconade formations.

In order to obtain the specific relation between the heads of two or more water beds it is necessary to measure them in the same well as it is drilled. As nothing along this line has been accomplished, no exact comparisons can be made. These relations would furnish excellent data when one stratum was struck as to whether further drilling would yield a better or less head and the approximate pressure which would then be available.

The contour map showing the elevation of the water level from the Roubidoux sandstone gives an approximate idea of the various heads obtained in different parts of the state from a single sandstone. So little data was collected on the Gasconade formation that a similar map for it was not warranted. A great deal of data was worked over from the supposed St. Peters area but such a variation in water level was found, that a contour map was almost impossible. A peculiar instance of this problem was that





the water head from the sandstone called St. Peters by most drillers increased away from the supply area. A satisfactory explanation for this has not yet been offered. The water level varies from 300 to 700 feet above sea level in the northeast Missouri province.

Effects of Pressure on the Yield of a Well.

The yield of a flowing well varies according to the pressure at the point of discharge, other things being constant. Consequently for the maximum yield for a given locality the lowest available spot should be chosen. Pressure is also the controlling factor in the transmission of water through porous rocks. Experiments have proved that doubling the pressure more than doubles the flow of water. The waters of Missouri are not generally under so great a pressure as those of Iowa and the Dakotas and as a consequence there are not as many flowing wells, but the pressure is large enough to drive water through the rocks and suffice for the needs of deep wells in most localities.

Advantage of a Large Hole.

One of the reasons for so much variation in yield of artesian wells is on account of the difference in diameter of the hole.* "The cross-section of a tube varies with the square of the diameter, thus disregarding other factors, an eight inch pipe would carry 16 times as much as a two inch pipe. But the larger the diameter the less the frictional resistance; hence the difference in favor of the larger pipe is still greater. Taking into account both cross-section and frictional resistance the discharge of pipes varies as the 2.5 power of the diameter."

The yield also depends upon the amount of water stratum exposed in the well. This varies according to the thickness of the bed and the distance penetrated by the drill. When the hole is uncased below the top of the water bed and the entire stratum is penetrated the maximum transmission might be expected. Thus a thick water bed will not only hold and carry more water but deliver more than a thin one.

Effect of Texture and Porosity.

Texture and porosity of the water rock effect the yield of a deep well. Gravels give up their store of water much more rapidly than fine sand. Doubling the size of the effective grains of sand raises the yield by four. Stratified rocks yield their water more readily along horizontal planes and a drill hole is fed from the sides by horizontal currents more rapidly than from the bottom. Texture and porosity both decrease as the rock is buried deeper below other sediments, and this causes a decrease in yield as the water rocks are covered more and more by a vast amount of overlying material.

Hypcthetical Problem on the Velocity of Underground Flow.

The Clinton wells get their supply from southern Morgan and Miller counties, a distance of about 50 miles. The average annual precipitation of Morgan County is 38 inches. For an approximate example, assume that 25 per cent or 9½ inches of the rainfall seeps into the ground as ground water at the point of intake. The average porosity of the Roubidoux sandstone is about 10 per cent as measured from hand specimens. Thus without raising the water level in Morgan and Miller counties it is necessary to suppose that the water of each previous year shall have a direct downward movement of 95 inches or 7 feet and 11 inches. The movement of the water along the dip is the cause of the lowering of the water level.

*Iowa Geological Survey Vol. 6, p. 14.

Since the dip of the rock is about 20 feet to the mile, the horizontal component of the water movement each year equals $\frac{5280 \times 8}{20}$ or about 0.4 miles. Therefore to travel 50 miles, or from Miller County to Clinton the necessary time is about 125 years.

This is only a hypothetical case and has many possibilities for incorrect assumptions, but serves to show the general rate of travel of underground waters.

*Van Hise estimated that the rate of flow through the Potsdam sandstone in Wisconsin region was 200 years for a distance of 150 kilometers or about 100 miles.

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*Monograph 47, U. S. Geological Survey, p. 585.

CHAPTER V.

COST AND ADEQUACY OF DEEP WATER SUPPLIES.

Comparative Cost of Artesian Water.

The drainage surface of Missouri is such that numerous rivers are well distributed over the state. Cities and towns naturally look to these rivers as the most economical means of obtaining an inexpensive water supply, but lately the demand has been for the best water, purity being considered above everything else. In many cases this has led to the installation of the deep well system; although the deep well can never replace other systems in Missouri as it has in Iowa because of the more general distribution of surface streams. Moreover the artesian conditions are not favorable throughout the entire state of Missouri, and the areas where artesian water can compete with good river supply are limited. In the towns not adjoining suitable rivers in northeast, central and southwest Missouri, the deep well source of supply should be considered and compared with other sources before a town installs a permanent system.

No city supply should be chosen until all possible means have been carefully investigated. Some towns in Missouri have been content with a very deficient river supply, where artesian water could have been obtained (probably not as cheaply) but with a better water and a much reduced possibility of contamination. Yet a town would be unwise to consider deep wells alone and install an expensive plant, when another source might be much more economical all things considered. It is not the purpose of this report to definitely advise any community to install a deep well system, but merely to place it in a proper light, in order that it may receive just consideration. Whatever source may be chosen by a town or corporation, the information as to probable depth, quality and quantity of artesian water will be of value to every locality.

The cost of drilling in Missouri averages from $2.50 to $3.00 a foot for wells not over 1200 feet deep, and over that depth the drilling is a little more expensive. The cost of casing varies with the size of the pipe and a price list may be obtained from any of the standard dealers through their free catalogues. Approximately the prices run as follows.

Inside diameter	Price per ft.		
2″	$0.23	7″	$1.50
3″	.35	8″	1.65
4″	.60	9″	1.90
5″	.95	10″	2.30
6″	1.25	12″	3.00

Under the average Missouri conditions water may be obtained within 800 feet of the ground surface. As the average water level stands at about 200 feet below the surface while being pumped, it is generally necessary to lift the water a distance of from 150 to 250 feet to bring it to the top of the well.

For a practical problem, assume that such a well pumps 200,000 gallons per day, with machinery of 60 per cent efficiency (electric motor-driven pump assumed), where power costs 6 cents per kilowatt hour:

Such a well should be a 10 or 12 inch bore, and the practical cost, including the casing would be about		$2500.00
Cost of installation of machinery		2500.00
Total investment in the plant		$5000.00
Power required to lift 200,000 gals. per day 200 ft.	3861.2 ft. lbs. per second.	
Power reduced to K. W.	5.24 K. W.	
Power necessary with machinery 60 per cent efficiency	8.74 K. W.	
Power cost per year		$4510.00
Cost of operation		4510.00
Fixed charges, including interest, depreciation, etc., estimated at		750.00
Cost of one year's discharge (73 million gals. lifted 200 ft.)		$5260.00
One million gallons lifted 1 foot cost		0.37
1000 gallons lifted 200 feet cost		0.073

Steam power is much more expensive, and has not been considered in this problem, as almost every town with a lighting plant can obtain electrical power more cheaply.

Knowing the conditions for any locality a practical comparison can be made between the cost of artesian water, and that of other water supplies.

Quality of Artesian Water.

Of the many sources of water supply, artesian wells are the least likely to be contaminated with bacteria. Typhoid bacilli are apt to pass through filtration plants and cause serious epidemics unless the plant is working constantly at its highest efficiency. This demands expert care which most small towns can not and do not afford. The waters from shallow wells and cisterns are never considered free from contamination.

Artesian waters have their source hundreds of feet below the surface and are free from bacteria because these microscopic organisms do not exist at that depth in the absence of light and oxygen. Consequently the only possible means of pollution is from surface waters through a faulty casing. This seldom occurs, but waters from the wells should be tested at regular intervals to ascertain whether or not surface water is creeping in. From the sanitarian's point of view, artesian well water is above suspicion and persons using it may rest assured of its healthful qualities.

Although deep well water is free from living organic matter, it contains a great deal of soluble mineral matter. In most cases this is not too objectional for domestic uses, but often is undesirable for factories using condensers and boilers. Water containing more than 2000 parts per million of mineral matter is unpalatable. This amount may be taken as the maximum allowable in a water supply for city use and particularly for drinking. The general observation and testimony of physicians is that this limit is practical and safe. However it can not be confidently asserted that the use of such waters might not have a deleterious effect upon a few individuals.

The standard for a boiler supply is somewhat different. In this case it is desirable for the water to contain as little soluble matter as possible so that the scale formed in the boiler will be a minimum. It is also necessary that the water should carry a very small amount of suspended matter. The chief difficulty in Missouri artesian water is the large soluble content. No special investigation has been made of the different waters and a discussion for individual localities is impossible. In a number of places deep well water is used successfully for boiler purposes, although it usually demands some treatment.

Objectionable Compounds in Artesian Waters.

The presence of lime and magnesia chiefly in the form of carbonates and sulphates, and occasionally as chlorides and nitrates, renders a water hard. The carbonates cause temporary hardness (removable by boiling) but the sulphates and other compounds cause permanent hardness. It has been shown by chemists that two ounces of soap are neutralized or wasted in each 100 gallons of water for each grain per gallon of calcium carbonate. The lime and magnesium carbonates are precipitated in boilers forming a deposit which can usually be removed by blowing out, unless accompanied by other scale forming substances. A very hard objectionable scale is precipitated from the sulphates of lime and magnesium under the temperatures occurring in steam boiler operation, especially if the water contains other suspended matter.

Simple Softening Processes.

A simple process of softening water is by chemical precipitation. The carbonates may be removed by the addition of lime, a greater quantity of lime being required in case of magnesium carbonate. Sodium carbonate is used to precipitate the sulphates. Some lime must be added to remove the magnesium sulphate completely. The sodium sulphate resulting from this reaction is very soluble but unobjectionable in the amount likely to be present. The chlorides and nitrates may be removed in the same way as the sulphates.

Another common method of softening water is by heating in a feed water heater. Where the water can be heated with exhaust steam and fed to the boiler at about 200° F., this process is economical and successful in the cases where the water contains the carbonates of lime and magnesium. It is not satisfactory where the water contains the sulphates because these are not precipitated until a temperature in the neighborhood of 300° F. is reached. The maximum temperature to which the water can be heated in an exhaust steam feed water heater is about 200° F.

CHAPTER VI.

IDENTIFICATION OF THE ST. PETERS AND ROUBIDOUX SANDSTONES.

It is the purpose of this chapter to justify the correlation of the first water bearing sandstone on the west and north of the Ozarks with the Roubidoux sandstone. In previous works the first water sandstone encountered has always been called the St. Peters sandstone. The change has been made here for two reasons: first, because of the general absence of the St. Peters sandstone in the western and central parts of Missouri, and second, because of the similar characteristics and close resemblance of the first sandstone in western Missouri to the Roubidoux.

The true St. Peters sandstone extends from the northern part of Jefferson County through the northeastern corner of Franklin County, across the Missouri River through Warren and Montgomery Counties. It probably underlies the northeastern corner of Missouri and connects with the St. Peters sandstone of Iowa. The formation extends into Callaway County where it pinches out, becoming discontinuous. In southern Boone County the St. Peters occurs in synclines at the top of the Jefferson City formation and the connecting beds between the synclines were removed before the overlying Devonian was deposited. The width of the sandstone in the synclines observed was always less than 1000 feet.

Throughout Moniteau and Morgan Counties, especially around Versailles, this sandstone is known to outcrop in patches, but nowhere to form a continuous bed. Five miles south of Sedalia synclines of sandstone similar to those of Boone and Callaway Counties were found at the top of the Jefferson City formation. Here the sandstone was only a few feet thick and the maximum width noted was about 35 or 40 feet. South of Sedalia no continuous sandstone in the horizon of the St. Peters has been described. This evidence shows a decided thinning of the St. Peters sandstone west of Montgomery County; that the area of central Missouri at least as far west as Sedalia was once covered with this sandstone, but that it was removed by erosion, excepting in the synclines, as far east as Callaway County, before Devonian time. At any rate the St. Peter sandstone does not outcrop in a continuous bed anywhere west and south of this county.

A formation may not outcrop in a region and still form an important water bearer for that region. Definite determination of this may be made by a study of the well sections throughout the area.

In the Wabash R. R. well section at Moberly there is a water bearing sandstone at 642 feet below the surface. The city wells also obtain water from about the 600 foot level. This sandstone furnishes excellent water but the quantity is limited. Another sandstone was encountered, according to Dr. Shepard,* at 1105 feet below the surface. Dr. Shepard has called this second sandstone the St. Peters, while in this work the one at the 600 foot level was given that name.

In the section by Dr. Shepard there have been inserted 95 feet of Niagarain, 234 feet of Hudson and 131 feet of Trenton above the second sandstone. None of these formations has been reported in any section west of Callaway County, and they do not average so great a thickness outside of Pike County where they reach a maximum for Missouri. The first water sand comes into the section just below the Devonian which is the proper place for the St. Peters sand provided the upper Ordovician and Silurian formations are absent. As shown in the previous paragraphs these formations do not outcrop west of Callaway County, and west of Pike County rarely total 100 feet in thickness.

In the Columbia well section no trace of the St. Peters sandstone was found. The Centralia section shows the Roubidoux sandstone at 1000 feet below the surface with thin lenses of sand between 500 and 600 feet, but bearing no important water. In the Marceline section the Roubidoux sandstone occurs at 1104 feet below the surface. This is identified as the Roubidoux sand because of the large amount of magnesian lime above the sandstone, a condition agreeing exactly with that of the Chillicothe section. The last evidence is almost certain proof, because the only magnesian limestone above the Jefferson City formation is the Joachim which seldom reaches 50 feet in thickness. Consequently where a sandstone is encountered below 200 or 300 feet of magnesian limestone it can be referred with certainty to the Cambrian and in the Moberly section of Shepard there is nothing in the description of the various strata to influence the classification to the contrary. The limestone above the sand is flinty and blue corresponding readily to the Jefferson City limestone above the Roubdoux sandstone. Assuming that the second sandstone at Moberly is the Roubidoux, it then follows a general northwest dip from Centralia (115 ft. below sea level) to Moberly (220 ft. below sea level) to Marceline (250 ft. below sea level). This dip is small, but the line along which the dip is measured is parallel to the axis of the northwest-southeast trough of the coal measures extending down into Audrain and Callaway Counties and little dip is to be expected. Moreover it is better to assume that the rocks in this district dip uniformly, corresponding with the surface formations, until definite proof has shown the conditions to be different.

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*U. S. Geological Survey, Water Supply Paper, 195, p. 102.

In a Higginsville* section, Dr. Shepard has placed the St. Peters sandstone at 1071 feet and the Roubidoux at 1371 feet below the surface. It is the opinion in this work that the Roubidoux is the sandstone at 1071 and the Gasconade at 1371. The reasons for this are similar to those in the Moberly section. One hundred and ninety-five feet of Kinderhook and 281 feet of Trenton are placed above the so-called St. Peters sandstone. The Mississippian formations are exceedingly thin in this part of the State, and the Kinderhook rarely equals 50 feet in any section along the outcrop. The Trenton is nowhere present this far west in Missouri.

†Dr. E. O. Ulrich gives a section of a Kansas City well with the St. Peters sandstone occurring at 1321 feet below the surface. Granite occurs at 2400 feet in the same; the coal measures are 750 feet thick. Here the Mississippian and Devonian formations which rarely equal 300 feet along the outcrops nearest this section, have been expanded into 600 feet, and a thin pinching sandstone (the St. Peters), very seldom seen along the outcrop has been given a definite place, while the 2000 feet of continuous Cambrian sediments have been cramped into half that amount.

West of Moberly no St. Peters sandstone furnishes water and in most wells there is almost a total absence of sandstone until the Roubidoux is reached. From the contour map showing elevation of the Roubidoux sandstone it is seen how regularly the sandstone dips away to the west and northwest. In each new well section in western Missouri the sandstone has been called the Roubidoux because of the gentle northwest dip agreeing with neighboring sections, the amount of magnesian lime above the sand, the character of the formations, and the similarity of the water. For these reasons the author thinks that the most logical conclusion is that the St. Peters sandstone is absent, and that the first important water sand of western and central Missouri is the Roubidoux.

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*U. S. Geological Survey, Water Supply Paper, No. 195, p. 38.
†U. S. Geological Survey, Water Supply, Paper No. 195, p. 86

NOTES ON THE SECTIONS.

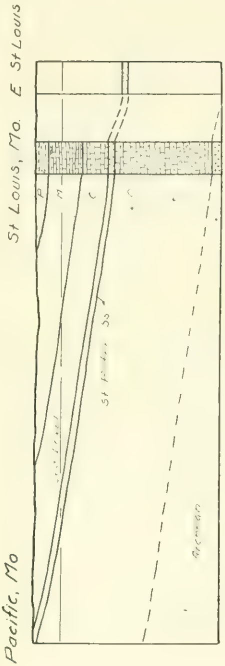
The following sections are to give a general idea as to how the rocks dip over large areas of the state. The vertical scale in all the sections is 1 inch equals 2000 feet of strata; the horizontal scale varies with the individual drawing. The sandstones carrying the water have been conventionalized, with small dots indicating sand, and have been labeled especially in order that they may be easily traced.

The logs of the sections in Missouri are given under the corresponding counties. The logs outside Missouri have the following references:

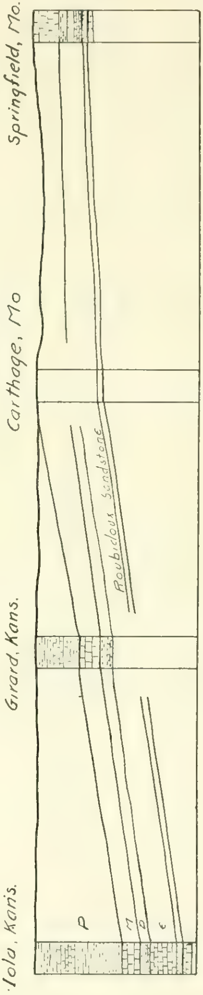
Iola, Kansas Section, Univ. Geol. Sur. Kansas, Vol. 9, pl. 16.
Bedford, Iowa Section, Iowa Geol. Sur. Vol. 21, p. 1183.
Bloomfield, Iowa Section, Iowa Geol. Sur. Vol. 21, p. 624.

Legend

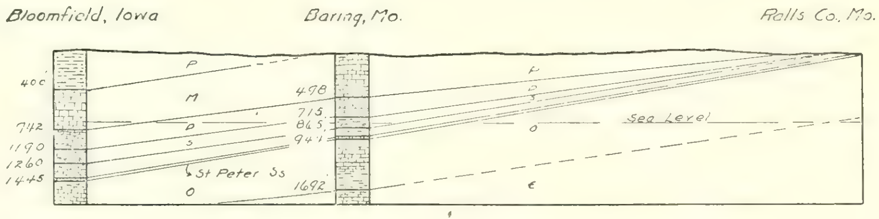
P	Pennsylvanian
M	Mississippian
D	Devonian
S	Silurian
O	Ordovician
€	Cambrian
Ar	Pre-Cambrian



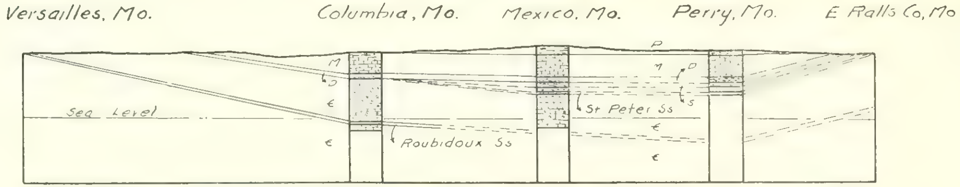
SECTION 1. PACIFIC. MO.-ST. LOUIS. MO.
Hoz. Scale 1" = 10 miles



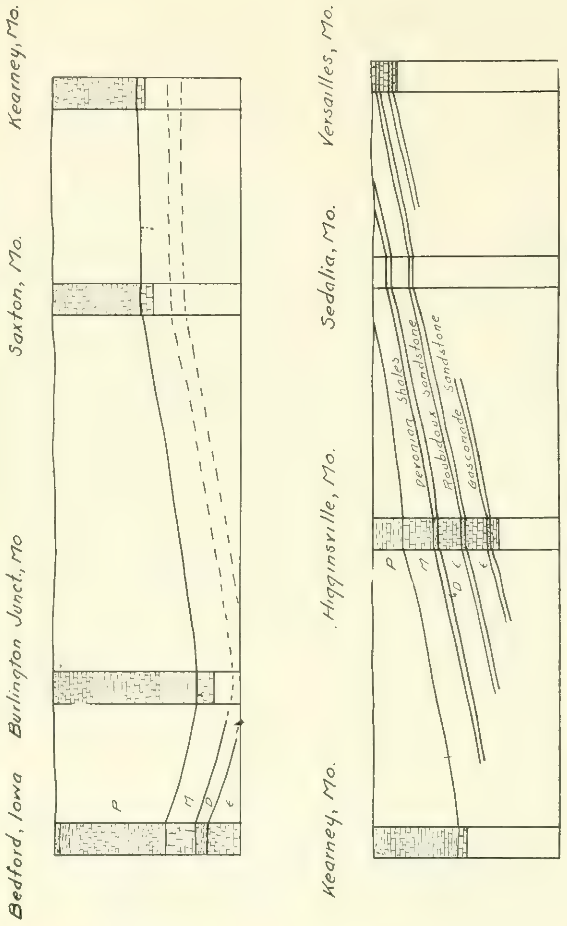
SECTION 2. IOLA. KANS.-SPRINGFIELD. MO.
Hoz Scale 1" = 20 miles



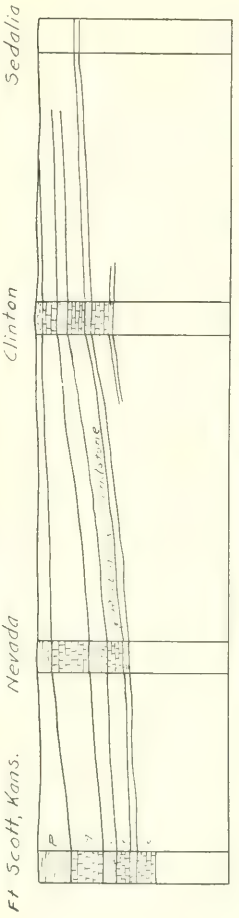
SECTION 3. BLOOMFIELD. IOWA-RALLS CO. MO.
Hoz Scale 1" = 24 miles.



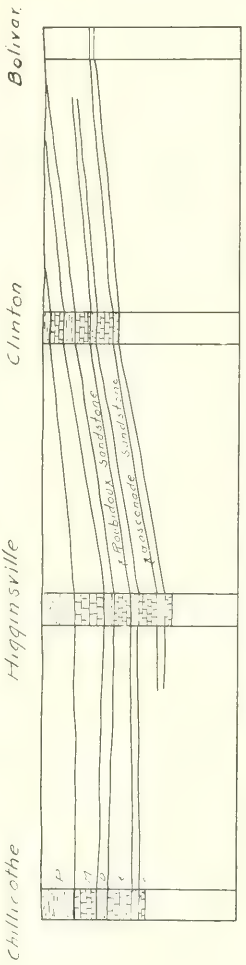
SECTION 4. VERSAILLES. MO. - PERRY. MO.
Hoz Scale 1" = 24 miles.



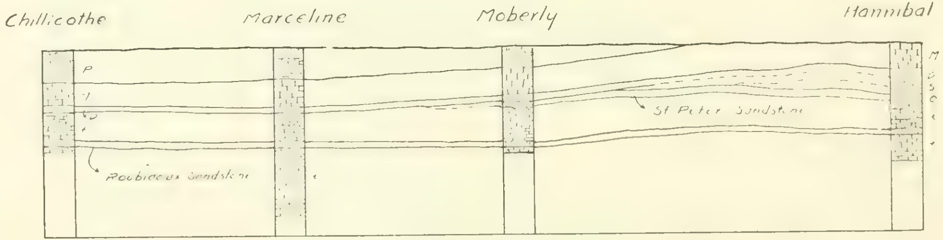
SECTION 5. BEDFORD. IOWA - VERSAILLES. MO.
Hoz. Scale 1" = 24 miles.



SECTION 6, FT. SCOTT, KANS. - SEDALIA, MO.
Scale 1" = 24 miles



SECTION 7, CHILLICOTHE - BOLIVAR, MO.
Scale 1" = 30 miles



SECTION 8. CHILLICOTHE - HANNIBAL MO.
Scale 1" 24 miles

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THE
UNIVERSITY OF MISSOURI
BULLETIN

ENGINEERING EXPERIMENT STATION
VOLUME 4   NUMBER 4

FRICTION TESTS OF LUBRICATING GREASES AND OILS

BY

A. L. WESTCOTT

MDCCCXXXIX

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
December, 1913

The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1, 1909.

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FRICTION TESTS OF LUBRICATING OILS AND GREASES.

INTRODUCTION

The objects to be gained by the lubrication of the bearings of machinery are twofold.

> 1.—By the interposition of a thin layer or film of oil between rubbing surfaces, they are kept partially separated, and wear due to rubbing contact is greatly reduced. The parts last longer and repair expenses are reduced by efficient lubrication.
>
> 2.—The coefficient of friction between two surfaces in sliding contact is greatly reduced by lubrication. The lost work of friction is therefore much less in a well oiled machine than in the same machine running without lubrication. Efficient lubrication thus reduces the amount, and therefore the cost, of the power required in a given plant.

The saving in repair expense and in cost of power is partially offset by the cost of the lubricant. The best lubricant for a given purpose is that which will give the maximum net annual saving.

Let **P** = the saving in friction horsepower due to lubrication.
M = the cost per year of one horsepower.
R = Annual saving in repair due to lubrication.
O = Annual cost of lubricant necessary to attain these savings.
S = Net annual saving, in dollars.

$$S = M\,P + R - O$$

That lubricant is best in any case for which **S** will have the largest value.

The friction reducing value of a lubricant may be determined by laboratory tests upon an oil testing machine. Its value to reduce wear in bearings is best determined, probably, by actual trial over a considerable period of time. But it is probably reasonable to assume that the wear of bearings is proportional to the coefficient of friction.

The coefficient of friction with a given lubricant varies greatly with the conditions under which it is used. The temperature of the bearing, the intensity of bearing pressure, and the speed of the surface of the journal are all factors in determining the coefficient of friction.

The tests of each lubricant reported in this bulletin were made under a great variety of conditions as to bearing pressure and temperature, to determine their relation to the coefficient of friction. These tests consist of:

> 1.—Tests of lubricating greases, made by the writer, or under his direction, to determine their lubricating value under a variety of conditions as to temperature, load on bearing, journal speed, and method of applying the lubricant.

2.—Tests of a number of engine oils and gas engine cylinder oils, under various loads and temperatures. These tests were made by Mr. G. F. Klein, and Mr. I. Dunbar as a thesis investigation, in the mechanical laboratory of the Department of Mechanical Engineering, University of Missouri, in the spring of 1913. The writer has carefully checked the computed data of Messrs. Klein and Dunbar, and presents it in a much condensed form.

TESTS OF LUBRICATING GREASES.

Cup greases are made by a process of saponifying some animal or vegetable oil, as cotton seed, lard or tallow. To the soap thus formed is added sufficient mineral oil to give the desired consistency. Manufacturers supply greases of several consistencies, adapted to different conditions of lubrication, each consistency or density having its number.

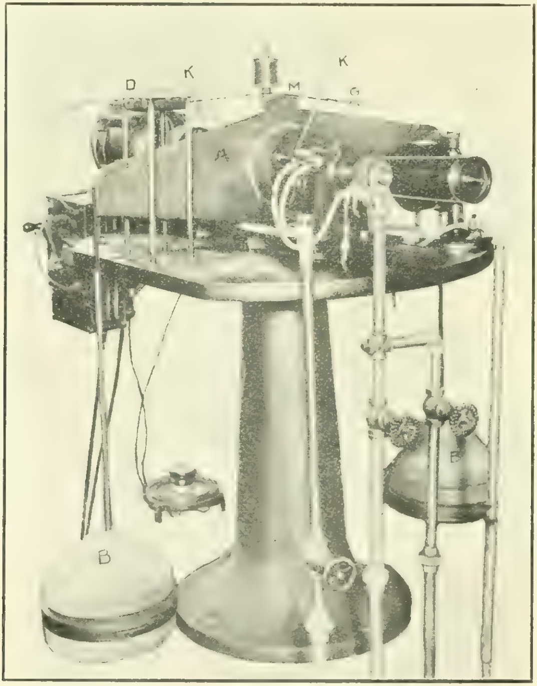

Fig. 1. Oil Testing Machine.

While grease lubrication is applicable to all sorts of machinery except steam and gas engine cylinders, it has its own special field where it has a marked advantage over oil. This field is machinery whose operation is intermittent, such as cranes and hoisting machinery. Grease cups of proper design will supply ample lubrication to the bearings of such a machine. They require no attention except to fill with grease when empty and, if of the hand compression type, to force grease into the bearing perhaps once or twice a day. No lubricant is wasted when the machine is not in operation, as is likely to be the case if sight feed oil cups and liquid lubricant are used.

It was the purpose of the investigations which form the basis of this report to test a number of greases for coefficient of friction and general suitability as a lubricant under a variety of conditions as to bearing pressure, temperature, and method of application of the grease.

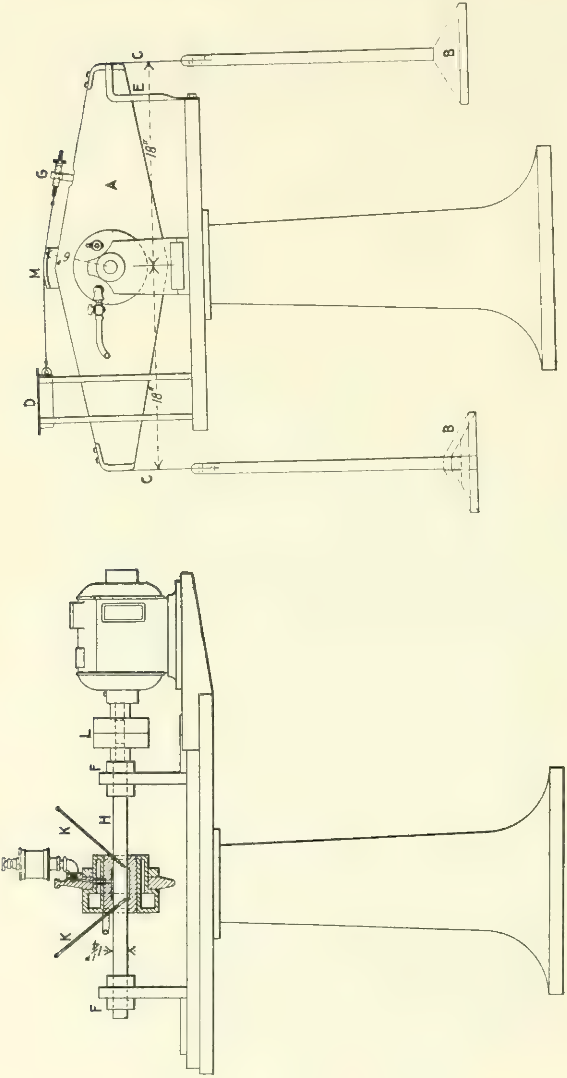

Fig. 2. Oil Testing Machine.

THE TESTING MACHINES

Tests for coefficient of friction were made upon a Golden oil testing machine. Fig. 1 is a general view of this machine, shown in the side and end elevations in fig. 2. The bearing consists of a babbitted sleeve which is fitted to a shaft H, fig. 2. This shaft runs in roller bearings F, and is driven by a motor through the coupling L. The motor is arranged with a reversing switch, so that it may run in either direction as desired. A cast-iron beam, A, is bored out at the center of its length to fit the bearing, to which it is fastened by screws. The ends of this beam are circular arcs struck from the shaft center. Flexible bands, C, are attached to A, and support the weights B, by means of which the load on the bearing is applied. The casting which forms the bearing is cored out so as to provide a space or jacket in which cold or hot water, or steam, may be circulated in order to control the temperature. At D a spring balance is supported upon four vertical rods that are screwed into the machine top. This balance is connected by means of a thin strip of spring steel to the post with screw adjustment at G. The steel strip leads over a part, M, cast on the upper side of A, and machined to form a circular arc whose center is the center of the shaft. The radius of this arc is 6 inches, and the height of the balance is such that it exerts a pull always in a horizontal direction. The weight on the end of the beam opposite to D must be made a little greater than that on the adjacent end, so that a positive pull will always be exerted whichever direction the motor is running. A pointer, E, attached to one end of the table top, enables the operator to bring the beam to any desired angular position. Holes are drilled in each end of the bearing for the insertion of thermometers K, the bulbs of which are brought close to the side of the journals, so as to get as nearly as possible a correct indication of the bearing temperature.

The formula for coefficient of friction is deduced as follows:

Let **W** = the total load on the bearing, pounds.
Let **P** = the pull on the spring balance, when running in a clockwise direction, pounds.
Let $\mathbf{P}_2$ = pull on balance when running anticlockwise.
Let **D** = diameter of journal, inches.
Let ϕ = coefficient of friction.

$$\phi W \frac{D}{2} = 6 \frac{P - P_2}{2}$$

$$\phi = (P_1 - P_2) \frac{6}{WD}$$

For any load, **W**, the constant $\frac{6}{\mathbf{WD}}$ may computed once for all, and the formula takes the form,

$$\phi = C\ (P_1 - P_2)$$

As originally constructed, the machine differed in several details from that which is shown in fig. 2. Instead of the post and screw adjustment at G, the balance was connected by a light chain to a pin at M, the idea being to take up or let out the chain link by link as required. Also the weights B were suspended by chains at C. It was found that these chains were a very unsatisfactory arrangement. It was necessary, in order to get reliable data, to keep the beam always in exactly the same angular position. A very slight change in the position of the beam would make a considerable difference in the pull on the balance. A chain consisting of a series of rigid links is not sufficiently flexible for the purpose. Changes in the angular position of the beam produced slight changes in the radii to the center lines through the weights B, and this of course meant an upsetting of the condition of equilibrium between the pull of the balance and the frictional turning moment. It was necessary, therefore, to adjust the beam position with great care, so as to be exactly the same when running in each direction. The pointer E was added for this purpose. Later, the chain hangers were replaced by thin steel bands at C. This change produced a marked improvement in the operation of the machine. It was still found to be desirable to keep the beam in one position, and to accomplish this better, the screw adjustment at G was added.

The bearing as supplied by the makers was 2 5-8" in diameter and 5" long. With the largest load that the suspending chains would safely carry, this gave only about fifty pounds per square inch of projected area. It was desired to carry the bearing pressures much higher than this. The length of bearing was therefore reduced to 1 1-2", as shown in fig. 3, there being two rings of 3-4" length each. The temperature was determined by a thermometer inserted into the jacket as shown in fig. 3, which also shows the manner of applying the lubricant.

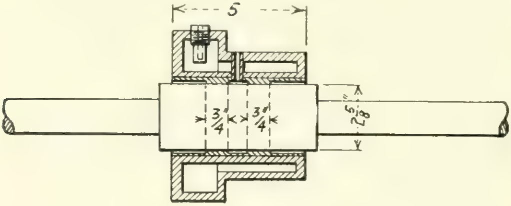

Fig. 3. Bearing.

The bearing of fig. 3 was not very satisfactory. It appeared that the proportion of length to diameter was bad, at least for grease lubrication. The grease was applied by means of a hand operated grease cup of the compression type. The counterbore between the two bearings, where the grease was forced in, was large enough to form a reservoir, and it was thought that the grease would feed in so as to maintain constant lubricating conditions. This did not prove to be the case. After the application of grease the friction, momentarily reduced thereby, would soon begin to increase steadily. A plot of friction against time, under these conditions, would look like the profile of a rip saw; a series of lines inclined more or less steeply to the horizontal, and connected by verticals where the grease cup was operated.

With a view to getting a more satisfactory form of bearing, the change indicated by fig. 4 was made. The diameter was reduced to 1 1-4″ and the length increased to 2″. This form of bearing proved to be a great improvement. It was still found, however, that intermittent feeding of the lubricant produced variable results for the coefficient of friction. An automatic grease cup, with a spring actuated plunger, designed to give a constant feed, gave much better results.

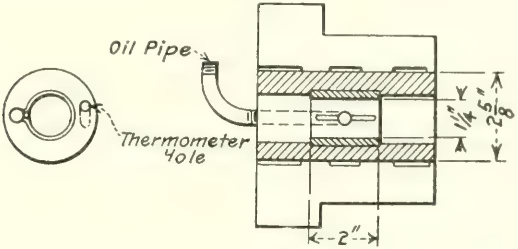

Fig. 4. Bearing.

LUBRICANTS EMPLOYED IN THE TESTS

Three series of grease tests are employed in this report, also tests of an engine oil for the purpose of comparing oil with grease under the same conditions. They will be classified as follows:

> Series A. Tests of cup greases of different densities, using a hand operated grease cup with intermittent feed, the bearing of fig. 3 being employed. The oil tests referred to are included in this series.
>
> Series B. Tests of the same greases as in series A, but with the bearing of fig. 4 employed, and for the most part using a grease cup having a constant feed.
>
> Series C. Tests of six different greases to determine their behavior when applied in a grease cellar on top of the journal, with a view to their flowing into the bearing by gravity when warmed.

Greases from two makers, designated as X and Y, were tested in series A and B. Greases from six different makers, designated by numbers 1 to 6, were tested in Series C.

The consistency of the X greases is indicated by a number; No. 00 being the hardest, No. 6 a semi-liquid, and the other numbers forming a graduated series between. The Y greases are likewise numbered, the hard grease having the highest number, while No. 1 is very soft. No. 5 Y is about the same consistency as No. 00 X.

The greases of Series C may be described as follows:

No. 1. Soft, spongy, fibrous in appearance, bright yellow color.
No. 2. Hard, bright yellow color.
No. 3. Soft, dark brown color.
No. 4. Very hard, light brown color.
No. 5. Extremely hard, looks and smells like soap.
No. 6. A graphite grease, soft, black.

The tests upon each grease in series A and B were carried out as follows:

The load on the bearing was varied, for each grease, through a range of from 46 to 148 pounds per square inch in series A, and from 53 to 154 pounds in series B. For each load, the test was made at temperatures varying through a wide range; beginning at room temperature and gradually increased. During the first three tests of series A, steam was not available for use in the bearing jacket, the elevation of temperature in those cases being due to the heat generated by friction.

In preparation for series C, two oil holes were drilled through the bearing, at angles at about 30 degrees with the horizontal, and on opposite sides of the vertical center line. Oil channels were cut from the inner ends of these holes, to insure the distribution of the lubricant over the bearing surface. A measured quantity of grease was placed in the oil holes, the bearing was loaded to the desired pressure, and the test was started, and continued without the application of any more lubricant until the lubrication failed. Neither water or steam was circulated through the jacket space, the rise in temperature being due entirely to the heat generated by friction. For the purpose of comparing this method of applying the grease with grease cup lubrication, tests were made of the same greases under the same conditions, but feeding the grease by means of a compression grease cup. All the tests of series C were made at one bearing pressure, 114 pounds per square inch.

TEST DATA

The results of Series A are found in tables I to V, and, in graphical form, in figs. 5 to 14; Series B, tables VI to XII, and figs. 15 to 28; Series C, tables XIII to XVIII, and figs. 29 to 34.

The curves plotted from series A and B show, first, the relation between coefficient of friction and temperature of bearing; and second, coefficient of friction and bearing pressure, temperature constant; the second plot being derived from the first one.

The curves representing Series C were plotted differently. Since the length of time that a given test was continued without renewal of the grease in the oil holes is an important factor in determining the value of each grease, time was plotted as abscissae, and coefficient of friction and rise of temperature as ordinates. Each curve shows the complete test of a grease, comprising one, two or three runs, made on different days.

Figs. 35 to 36 show the final set of derived data as to series A and B. For a selected bearing pressure and temperature, the coefficient of friction of each grease number was plotted against the grease numbers as abscissae the purpose being to show the most advantageous grease consistency for a given condition. Plots were thus made for two pressures and for two temperatures for each pressure.

An inspection of the tables and curves brings out some well defined relations. The values of the coefficient of friction shown in series A, made upon a bearing of large diameter and small length, are greatly in excess of values for the same grease when tested on the bearing shown in fig. 4, series B. For example, compare tests of X of grease, No. 3 density, table II, and table VII; and Y grease No. 1 density, tables IV and XII. As has been stated before, the large and short bearing, consisting of two lengths of ¾" each, proved to be a poor form for grease lubrication. The film of lubricant seemed to have little endurance, and the only way to get results particularly with the denser greases, was to force in grease frequently.

Another difference in conditions between the tests of series A and B is the difference in velocity of journal. It will be noted that in series A the surface speed of journal was about double that of series B. The relations between speed of journal and coefficient of friction are discussed in a later paragraph.

The condition of the bearing as to smoothness due to long running seems to have a marked influence upon the coefficient of friction. The test of Y grease No. 2, series B, was made when the bearing was new. The other tests of this series, however, were made subsequently to those of series C, when the bearing had become worn by long use. The effect of this in reducing friction is shown by a comparison of tests of tables X, XI and XII. This comparison shows that No. 2 gave much larger values than either of the other two.

Compare, also, X grease No. 6, table No. VIII, and No. 3, table No. VII. Grease No. 6 was tested upon the bearing shown in fig. 2, immediately after its construction. The new bearing and shaft were made with a clearance of .00075", while the other bearing had a clearance of .003", besides being well worn, as already described. The coefficients of friction for grease No. 6 are larger than those of No. 3, due doubtless to the closer fit of the bearing on the journal and the newness of the bearing.

The effect of a rise of temperature upon the coefficient of friction is almost always the same. The curves show this very clearly. The fluidity of a lubricant is increased by warming it, and its viscosity is decreased. This results in decreased friction up to that point where the bearing pressure is sufficient to overcome the tenacity of the oil film, so that there is contact between the rubbing surfaces. The tests do not indicate that, within the limits of bearing pressure which obtained, there is any disadvantage or danger of cutting the bearing incident to a temperature of 150 degrees F. In some instances the temperature was carried as high as 200 degrees, and as long as there was an ample supply of lubricant to the bearing, no harmful effects were noted. The "hot box" of practice occurs because the lubrication of the bearing has failed; the former being the effect of increase of friction due to the latter. There is nothing intrinsically objectionable in a bearing temperature much higher than is commonly permitted in practice, if good lubrication obtains; and these experiments show that much may be gained in the way of decreasing the lost work of friction.

The tests of series C served to show that the oil hole method of applying grease to the bearing is inferior to the method of forcing it in by means of a grease cup, the coefficients of friction in the former case being much larger than in the latter. An exception is noted in case of grease No. 4 where the advantage lies with the oil hole method. If instead of a small oil hole, a grease reservoir extending the length of the journal had been used, it is possible that the results of the comparison might be different.

Greases Nos. 1, 2 and 3 made a fair showing. Nos. 4, 5 and 6 did very poorly. In each of these cases the grease placed in the oil holes did not flow sufficiently to prevent the bearing from running dry. Two of these failures, Nos. 4 and 5, were extremely hard greases; while No. 6 was a soft graphite grease. In cases of Nos. 1, 2 and 3, two or more runs were required to use up the grease, it being not always convenient to make one continuous run. An inspection of the curves plotted shows that as a rule the coefficient of friction was high at the start, decreasing after a time as the bearing became warm and the grease flowed into the bearing. It was found that the lubrication at the best was very uncertain, the friction often fluctuating greatly.

Y GREASE NO. 5. LOAD ON BEARING, 74.1 lbs. per sq. in.

Time of Day.	Spring Balance				Bearing Temperature °F	Coefficient of Friction ϕ	Remarks
	P₁		P₂				
	lbs.	oz.	lbs	oz.			
11:33	*7	8			76	.0244	Readings marked * were taken immediately after forcing grease into the bearing.
35	7	9			79	.0276	
36	reversed		motor.				
38			*6	9	80	.0244	
39			6	8	80	.0276	
40			6	7	80	.0310	
40			*6	9	81	.0244	
46			6	7½	82	.0293	
47			6	7	82	.0310	
47			*6	11	82	.0210	
57			6	5¼	83	.0396	
57			*6	11½	....	.0201	
	reversed		motor.				
12:00	7	11½			...	.0325	
02	7	12½			82	.0350	
02	*7	8			....	.0210	

SECOND TEST AT SAME LOAD, BUT AT HIGHER TEMPERATURES

5:26	7	6½			110	.0178	
26	*7	5½			......	.0146	
29	7	6			118	.0162	
29	*7	5½			......	.0146	
	reversed		motor.				
30			6	12	120	.0162	
32			6	12	......	.0162	
32			*6	12½	......	.0146	
40			6	10	160	.0228	
40			*6	10	160	.0228	
	reversed		motor.				
42	7	8			164	.0236	
43	7	7½			160	.0220	
46	7	8			158	.0236	
47	8	0			......	.049	Unsteady.
47	*7	7½			......	.0220	
52	*7	10			185	.0260	
53	7	10			190	.0260	
54	7	9¾			......	....	
	reversed		motor.				
55			6	10	......	.0260	
55			*6	10	190	.0260	
6:01			6	10	......	....	

It will be noticed that the variation in friction referred to is much more marked at low temperature than at high ones, presumably because the grease flows better when hot

The best results, so far as producing constant and uniform conditions of lubrication are concerned, were obtained when using a grease cup with a plunger actuated by a helical spring so as to give a constant feed. When adjusted to feed grease steadily and uniformily, the coefficient of friction at a given load and temperature remained about constant. With the intermittent feed of the hand operated grease cup, results in this regard were not so good. In many of the tests, where observations were taken immediiately after feeding the grease, and at one minute intervals thereafter, the friction was seen to steadily increase, even with the bearing of the form of fig. 4, decreasing again to its former value upon again forcing in grease. This is illustrated by the following abstracts from the original log of tests of Y grease No. 5, shown in the table on page 12.

TABLE NO. 1.

X GREASE, NO. 1 DENSITY.

Series A. Loads, 46 to 148 pounds per square inch. See figs. 5 and 6.
Diameter of journal, 2 5-8″; length, 1 1-2″.
Compression grease cup used, with intermittent feed of the lubricant.

Load on bearing, 46 lbs. per sq. in. Surface speed of journal, 730 to 860 feet per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	86	.0675	Room temperature, 84 deg.
2	96	.0520	
3	104	.0440	
4	110	.0380	
5	114	.0410	Motor reversed.
6	119	.0390	
7	122	.0350	
8	125	.0350	Motor reversed.
9	127	.0350	
10	130	.0350	
11	131	.0330	Motor reversed.
12	132	.0320	
13	133	.0330	
14	135	.0300	
15	136	.0306	
16	137	.0324	

Load on bearing, 71.5 lbs. per sq. in. Surface speed of journal, 690 to 850 feet per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74	.0528	Room temperature, 75 deg.
2	86	.0426	
3	97	.0325	
4	103	.0324	
5	109	.0280	Motor reversed.
6	112	.0280	
7	116	.0282	
8	119	.0250	Motor reversed
9	123	.0244	
10	125	.0244	
11	126	.0244	Motor reversed.
12	127	.0244	
13	129	.0244	
14	131	.0224	Motor reversed.
15	135	.0240	
16	137	.0240	
17	138	.0244	Motor reversed.
18	138	.0228	

Load on bearing, 122 lbs. per sq. in. Surface speed of journal, 745 to 855 ft. per. min

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	71	.0344	Room temperature, 72 deg.
2	88	.0256	
3	101	.0220	
4	109	.0202	
5	113	.0192	Motor reversed.
6	118	.0183	
7	121	.0183	
8	124	.0126	Motor reversed.
9	128	.0154	
10	130	.0154	
11	131	.0160	Motor reversed.
12	133	.0160	
13	134	.0161	
14	137	.0148	Motor reversed.
15	138	.0148	
16	139	.0148	
17	140	.0150	Motor reversed.
18	141	.0150	

Load on bearing, 148 lbs. per sq. inch. Surface speed of journal, 690 to 850 ft. per. min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74–84	.0310	Room temperature, 77 deg.
2	91–98	.0214	Motor was reversed after each observation.
3	105	.0191	
4	113	.0188	
5	121	.0191	
6	128	.0142	
7	132	.0144	
8	139	.0142	
9	143	.0152	
10	145	.0144	

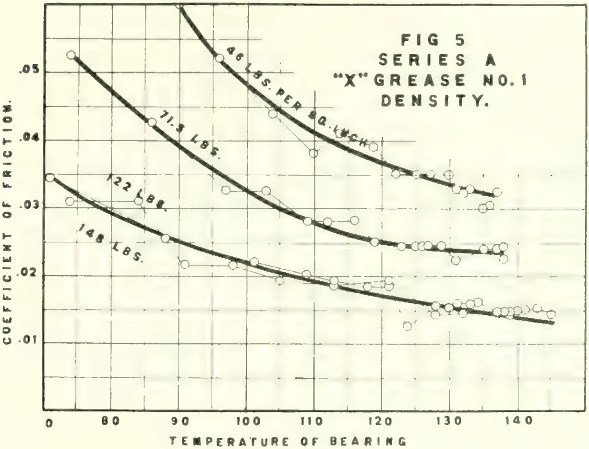

FIG 5
SERIES A
"X" GREASE NO. 1
DENSITY.

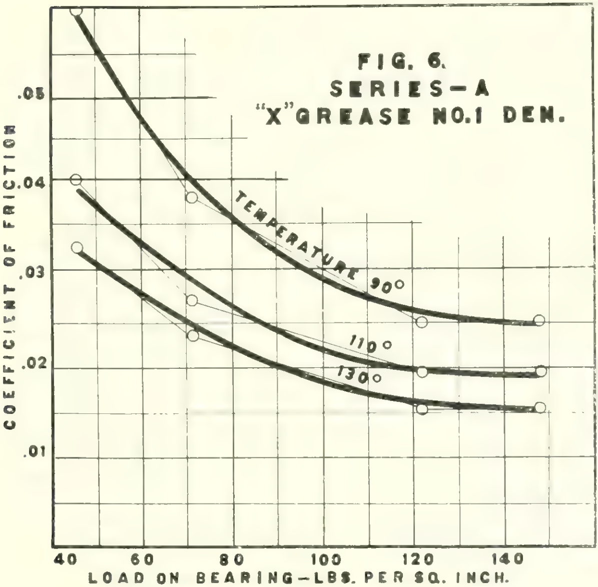

FIG. 6.
SERIES—A
"X" GREASE NO. 1 DEN.

TABLE NO. 2.

X GREASE, NO. 3 DENSITY.

Series A. Loads, 46 to 148 pounds per square inch. See figs. 7 and 8.
Diameter of journal, 2 5-8″; length, 1 1-2″.
Compression grease cup used, with intermittent feed of the lubricant.

Load on bearing, 46 lbs. per sq. inch. Surface speed of journal, 775 to 860 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	98	.0525	
2	105	.0391	
3	111	.0375	Motor reversed.
4	113	.0350	
5	115	.0350	
6	117	.0343	
7	121	.0327	Motor reversed.
8	124	.0344	
9	126	0327	Motor reversed.
10	127	.0300	
11	128	.0342	Motor reversed.
12	130	.0310	
13	131	.0346	

Load on bearing, 71.5 lbs. per sq. inch. Surface speed of journal, 750 to 845 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	76	.0495	
2	88	.0385	
3	100	.0334	
4	107	.0313	Motor reversed.
5	111	.0294	
6	115	.0272	
7	117	.0260	Motor reversed.
8	121	.0295	
9	124	.0265	
10	127	.0230	Motor reversed.
11	128	.0232	
12	130	.0230	Motor reversed.
13	131	.0230	
14	132	.0204	
15	134	.0254	Motor reversed.
16	135	.0192	

Load on bearing, 97 lbs. per sq. in. Surface speed of journal 690 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	90	.0365	
2	101	.0225	
3	109	.0240	
4	116	.0204	
5	120	.0210	Motor reversed.
6	123	.0217	
7	126	.0202	
8	130	.0210	Motor reversed.
9	135	.0210	
10	140	.0218	
11	139	.0172	Motor reversed.
12	138	.0164	
13	138	.0186	
14	140	.0195	Motor reversed.
15	146	.0115	
16	145	.0165	
17	144	.0172	

Load on bearing, 122 lbs. per sq. in. Surface speed of journal, 580 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74	.0244	
2	86	.0292	
3	97	.0202	
4	105	.0167	
5	110	.0182	Reversed motor.
6	115	.0180	
7	119	.0170	
8	122	.0160	Reversed motor.
9	125	.0160	
10	127	.0143	
11			Reversed motor.
12	132	.0142	
13	135	.0125	Reversed motor.
14	137	.0131	
15	138	.0131	
16	139	.0143	

Load on bearing, 148 lbs. per sq. inch. Surface speed of journal, 690 to 825 ft. per min

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	78	.0304	Motor was reversed at each observation.
2	92	.0267	
3	101	.0232	
4	112	.0167	
5	120	.0155	
6	125	.0167	
7	130	.0135	
8	133	.0132	
9	140	.0129	
10	140	.0152	
11	154	.0122	
12	151	.0133	

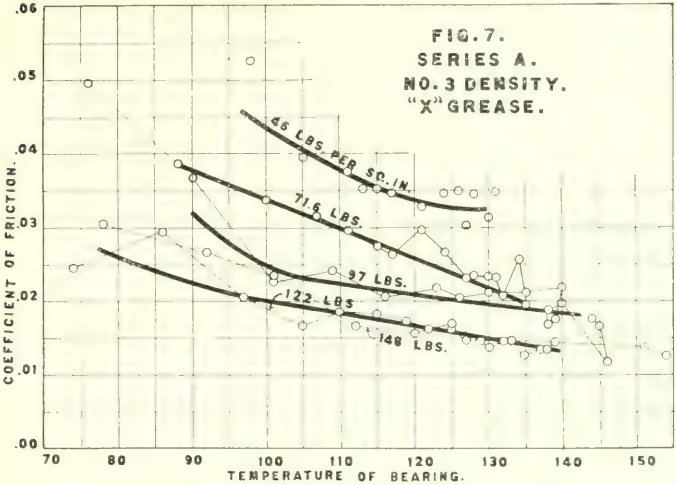

FIG. 7.
SERIES A.
NO. 3 DENSITY.
"X" GREASE.

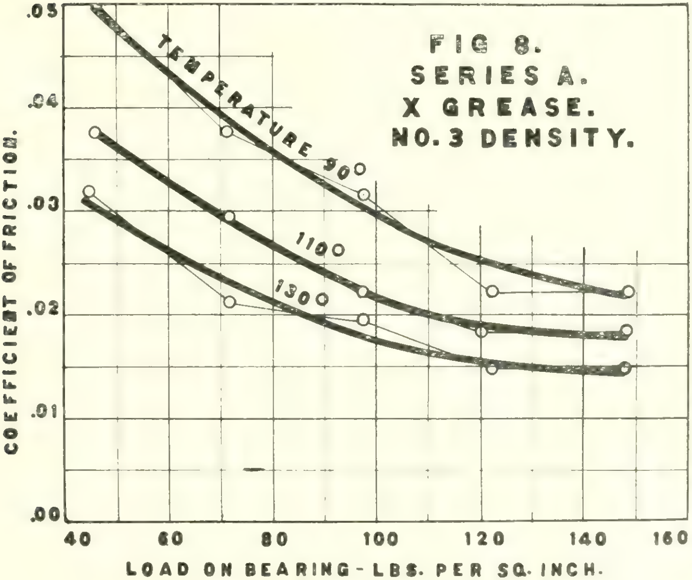

FIG 8.
SERIES A.
X GREASE.
NO. 3 DENSITY.

TABLE NO. 3.

Y GREASE, NO. 2 DENSITY.

Series A. Loads of 46 to 85 lbs. per sq. inch. See figs. 9 and 10.
Diameter of journal, 2 5-8″; length, 1 1-2″.
Compression grease cup used, with intermittent feed of the lubricant.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 46 lbs. per sq. inch. Surface speed of journal, 800 ft. per min.			
1	70	.0504	
2	80	.0460	
3	82	.0421	
4	90	.0400	
5	99	.0340	
6	123	.0355	
7	140	.0378	
8	180	.0300	

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 72 lbs. per sq. in. Surface speed of journal, 725 to 800 feet per min.			
1	69	.0365	
2	71	.0330	
3	83	.0294	
4	95	.0292	
5	115	.0240	
6	147	.0252	
7	208	.0232	
Load on bearing, 85 lbs. per sq. in. Surface speed of journal, 700 feet per minute.			
1	70	.0350	
2	80	.0282	
3	90	.0254	
4	100	.0247	
5	126	.0183	

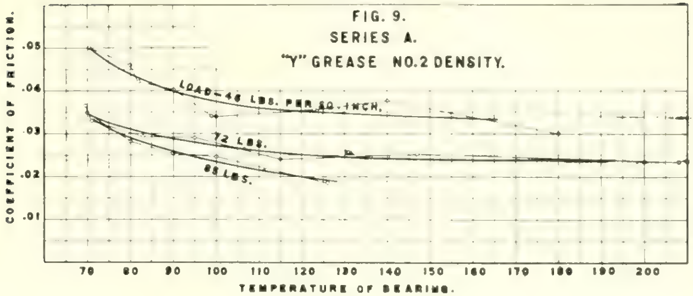
FIG. 9.
SERIES A.
"Y" GREASE NO. 2 DENSITY.

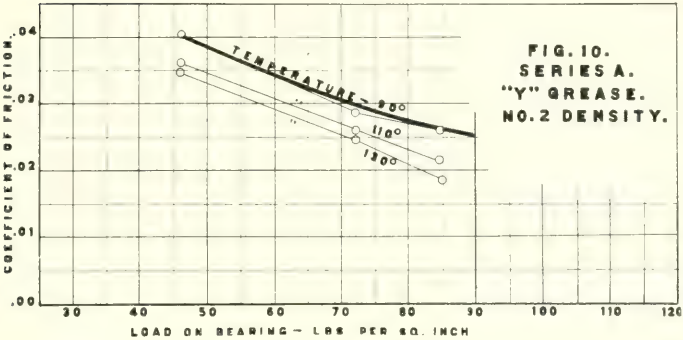
FIG. 10.
SERIES A.
"Y" GREASE.
NO. 2 DENSITY.

TABLE NO. 4.

Y GREASE, NO. 1 DENSITY.

Series A. Loads of 34 to 110 lbs. per sq. inch. See figs. 11 and 12.
Diameter of journal, 2 5-8″; length, 1 1-2″.
Compression grease cup used, with intermittent feed of the lubricant.

Load on bearing, 34 lbs. per sq. inch. Surface speed of journal, 820 to 855 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	77	.0479	Ran from 7 to 18 minutes at each temperature, with frequent observations of spring balance. Lubrication was very uniform at all temperatures.
2	92	.0390	
3	112	.0316	
4	145	.0275	
5	180	.0250	
6	209	.0222	

Load on bearing, 46 lbs. per sq. inch. Surface speed of journal, 760 to 870 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	78	.0370	Ran 20 to 28 minutes at each temperature.
2	82	.0380	
3	98	.0346	
4	116	.0258	
5	120	.0234	
6	145	.0242	
7	183	.0207	

Second test at load of 46 pounds.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	72	.0435	
2	78	.0375	
3	97	.0332	
4	116	.0265	
5	184	.0219	

Load on bearing, 59 lbs. per sq. inch. Surface speed of journal, 690 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	69	.0327	Ran 8 to 16 minutes at each temperature.
2	80	.0310	
3	100	.0275	
4	120	.0220	
5	146	.0204	
6	190	.0177	
7	208	.0190	

Load on bearing, 72 lbs. per sq. inch. Surface speed of journal, 760 to 845 ft. per min.

Number	Bearing Temperature, Degrees F	Coefficient of Friction	Remarks
1	71	.0348	Ran 9 to 16 minutes at each temperature.
2	82	.0284	
3	114	.0198	
4	143	.0195	
5	182	.0168	

Second test at load of 72 pounds. Surface speed of journal, 730 to 840 feet per minute.

Number	Bearing Temperature, Degrees F	Coefficient of Friction	Remarks
1	70	.0352	
2	82	.0272	
3	100	.0225	
4	114	.0206	
5	142	.0187	

Load on bearing, 85 lbs. per sq. inch. Surface speed of journal, 810 to 860 feet per min.

Number	Bearing Temperature, Degrees F	Coefficient of Friction	Remarks
1	70	.0300	Ran 7 to 24 minutes at each temperature.
2	88	.0231	
3	105	.0188	
4	125	.0168	
5	145	.0180	
6	185	.0169	
7	208	.0158	

Load on bearing, 110 lbs. per sq. in. Surface speed of journal, 755 to 825 ft. per min.

Number	Bearing Temperature, Degrees F	Coefficient of Friction	Remarks
1	80	.0206	Ran 6 to 10 minutes at each temperature.
2	101	.0177	
3	110	.0169	
4	125	.0144	
5	145	.0135	
6	188	.0129	
7	206	.0128	

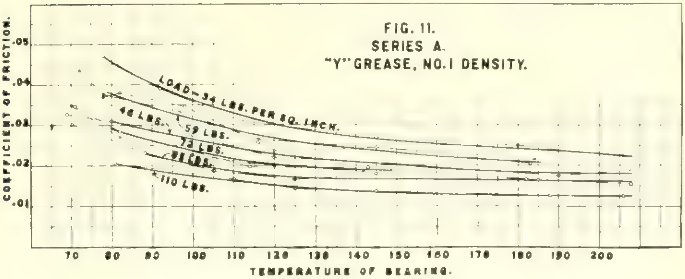
FIG. 11.
SERIES A.
"Y" GREASE, NO. 1 DENSITY.
LOAD—34 LBS. PER SQ. INCH.
46 LBS.
59 LBS.
72 LBS.
91 LBS.
110 LBS.
COEFFICIENT OF FRICTION.
.05
.04
.03
.02
.01
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TEMPERATURE OF BEARING.

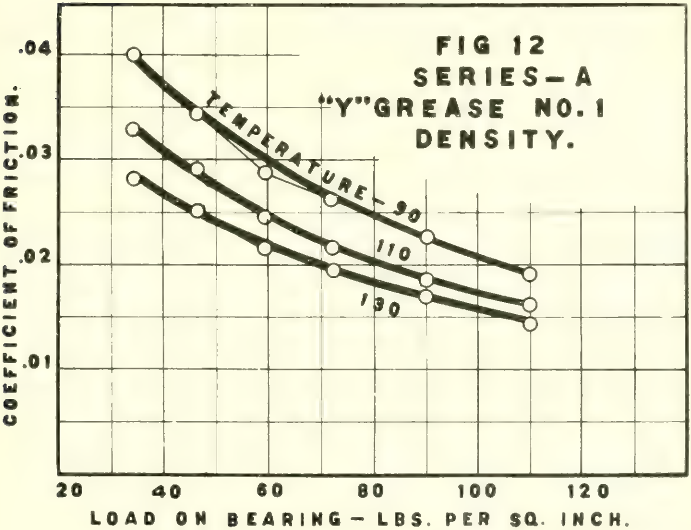
FIG 12
SERIES—A
"Y" GREASE NO. 1
DENSITY.
TEMPERATURE—90
110
130
COEFFICIENT OF FRICTION.
.04
.03
.02
.01
20
40
60
80
100
120
LOAD ON BEARING—LBS. PER SQ. INCH.

TABLE NO. 5. ENGINE OIL

Series A. Loads of 20 to 174 pounds per sq. inch. See figs. 13 and 14.
Diameter of bearing 2 5-8″; length 1 1-2″.

Tests of this oil were for the purpose of comparing oil with grease under the same conditions.

Load on bearing, 20 lbs. per sq. in. Surface speed of journal, 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	79	.0630	Room temperature, 79 deg.
2	82	.0541	Motor was reversed at each observation.
3	87	.0470	
4	90	.0455	
5	92	.0435	
6	96	.0405	
7	100	.0399	
8	105	.0362	
9	108	.0344	
10	109	.0389	
11	110	.0380	
12	111	.0330	
13	111	.0330	
14	111	.0330	

Load on bearing, 46 lbs. per sq. inch. Surface speed of journal 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	88	.0292	Room temperature, 90 deg.
2	93	.0236	Motor was reversed at each observation.
3	98	.0222	
4	101	.0206	
5	104	.0200	
6	106	.0198	
7	108	.0186	
8	109	.0186	
9	111	.0182	
10	112	.0190	
11	114	.0176	
12	115	.0178	
13	116	.0178	
14	117	.0178	
15	118	.0176	
16	...	.0178	
17	119	.0176	
18	120	.0176	

Load on bearing, 71.5 lbs. per sq. in. Surface speed of journal, 825 ft. per min

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	81	.0234	Motor was reversed at each observation.
2	86	.0209	
3	92	.0173	
4	96	.0170	
5	102	.0170	
6	107	.0146	
7	109	.0142	
8	110	.0142	
9	111	.0135	
10	112	.0135	
11	112	.0130	
12	113	.0130	
13	113	.0136	
14	115	.0136	
15	115	.0137	
16	116	.0129	

Load on bearing, 97 lbs. per sq. in. Surface speed of journal 690 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	89	.0138	Room temperature, 90 deg.
2	96	.0137	Motor was reversed at each observation.
3	101	.0133	
4	107	.0129	
5	107	.0123	
6	111	.0121	
7	114	.0119	
8	116	.0120	
9	118	.0120	
10	119	.0120	
11	120	.0120	
12	122	.0119	
13	123	.0119	
14	124	.0117	
15	...	.0121	
16	127	.0117	
17	127	.0105	
18	128	.0105	
19	128	.0105	
20	129	.0104	
21	129	.0105	

TABLE NO. 5. ENGINE OIL—Continued

Load on bearing, 122 lbs. per sq. in. Surface speed of journal, 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0196	Room temperature 77 deg.
2	83	.0144	
3	89	.0136	
4	94	.0099	
5	98	.0126	Motor reversed
6	102	.0113	
7	104	.0108	
8		.0113	Motor reversed
9	106	.0107	
10	108	.0099	
11	110	.0099	
12	.	.0095	Motor reversed.
13	111	.0092	
14		.0099	
15	113	.0107	
16	. . .	.0077	Motor reversed.
17	115	.0101	

Same load and speed, second test

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	81	.0151	
2	87	.0143	Motor reversed.
3	95	.0131	Motor reversed.
4	101	.0114	Motor reversed.
5	104	.0109	Motor reversed.
6	106	.0109	
7	109	.0110	Motor reversed.
8	111	.0108	Motor reversed.
9	113	.0108	
10	115	.0109	Motor reversed.
11	116	.0107	Motor reversed.
12	118	.0106	
13	119	.0106	Motor reversed
14	121	.0095	
15	123	.0091	Motor reversed.
16	124	.0098	Motor reversed.
17	124	.0098	
18	.	.0096	

Load on bearing, 148 lbs. per sq. in. Surfacespeed of journal, 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0172	Room temperature, 76 deg.
2	82	.0142	Motor was reversed at each observation.
3	90	.0120	
4	96	.0108	
5	101	.0108	
6	105	.0113	
7	110	.0121	
8	113	.0105	
9	114	.0094	
10	116	.0083	
11	118	.0082	
12	120	.0082	

Load on bearing, 174 lbs. per sq. in. Surface speed of journal, 755 to 825 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	84	.0134	Room temperature, 80 deg.
2	91	.0109	Motor was reversed at each observation.
3	96	.0100	
4	100	.0101	
5	106	.0101	
6	111	.0098	
7	114	.0082	
8	116	.0061	
9	117	.0060	
10	119	.0061	
11	120	.0060	
12	121	.0059	

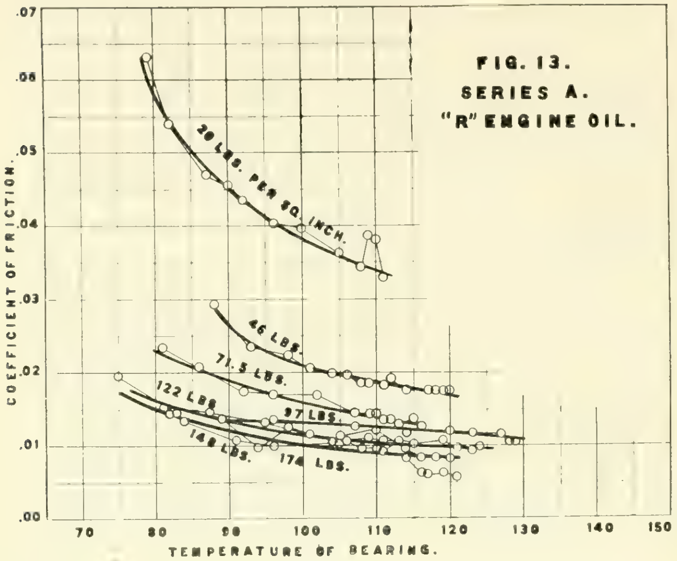

FIG. 13.
SERIES A.
"R" ENGINE OIL.

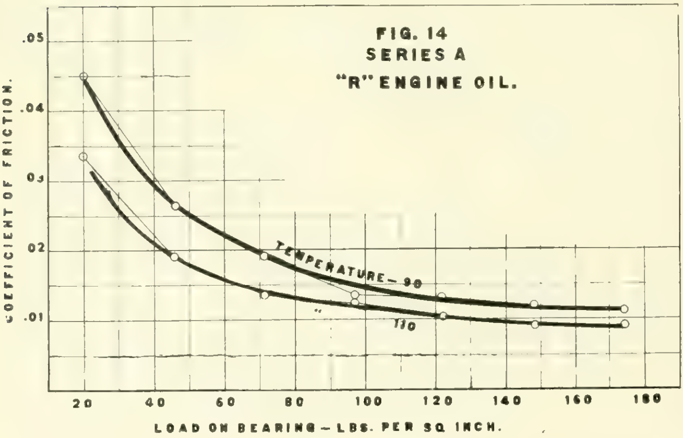

FIG. 14
SERIES A
"R" ENGINE OIL.

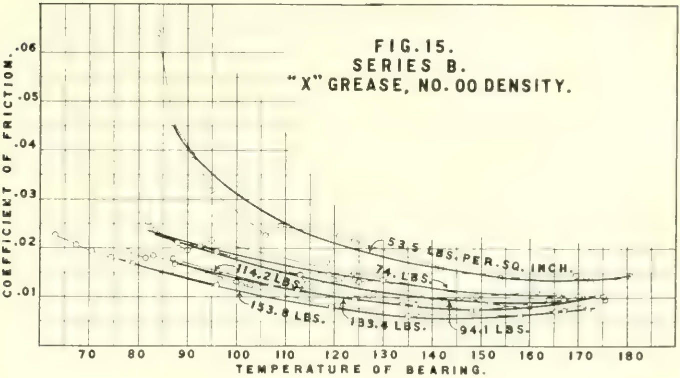

FIG. 15.
SERIES B.
"X" GREASE, NO. 00 DENSITY.

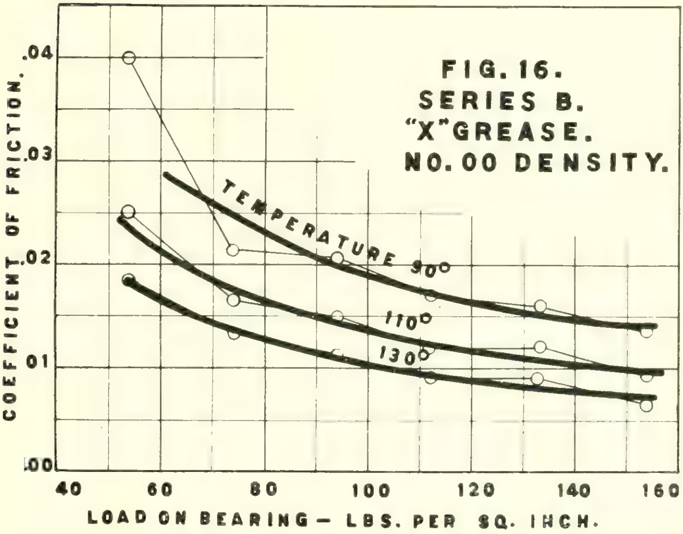

FIG. 16.
SERIES B.
"X" GREASE.
NO. 00 DENSITY.

TABLE NO. 6.

X GREASE, NO. 00 DENSITY.

Series B. Loads of 53.5 to 153.8 lbs. per square inch. See figs. 15 and 16.
Diameter of journal, 1 1-4″; length, 2″.
Grease cup used with spring actuated plunger.

Load on bearing, 53.5 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Co-efficient of Friction	Remarks
1	84	.0640	Room temperature, 52 deg.
2	77	.0457	Forced grease in by hand.
3	89	.0425	
4	91	.0390	
5	89	.0425	
6	109	.0290- .0246	Second reading after forcing grease in by hand.
7	106	.0224	
8	95	.0325	Warmed grease in cup to increase flow.
9	95	.0313	
10	121	.0224	
11	124	.0213	
12	142	.0167	
13	142	.0157	
14	154	.0145	
15	155	.0134	
16	170	.0145	
17	172	.0134	
18	180	.0145	

Load on bearing, 74 lbs. per sq. inch. Surface speed of journal, 415 ft. per min.

Number	Bearing Temperature, Degrees F.	Co-efficient of Friction	Remarks
1	84	.0236	
2	84	.0236	
3	82	.0232	
4	91	.0195	
5	93	.0219	
6	95	.0212	
7	119	.0146	
8	116	.0163	
9	121	.0138	
10	118	.0171	
11	124	.0150	
12	147	.0097	
13	148	.0106	
14	148	.0101	
15	162	.0114	
16	166	.0109	
17	162	.0114	

Load on bearing, 94.1 lbs. per sq. in. Surface speed of journal, 390 feet per min.

Number	Bearing Temperature, Degrees F.	Co-efficient of Friction	Remarks
1	88	.0210	Room temperature, 71 deg.
2	92	.0204	
3	96	.0191	
4	115	.0128	
5	115	.0128	
6	113	.0146	
7	124–130	.0134	
8	130	.0131	
9	125	.0131	
10	146–149	.0102	
11	142	.0089	
12	146	.0102	
13	152–160	.0080	
14	165	.0096	
15	170–175	.0102	
16	175	.0096	

Load on bearing, 114.2 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Co-efficient of Friction	Remarks
1	86–89	.0168	Temperature of room, 65 deg.
2	87	.0178	
3	89	.0173	
4	107	.0121	
5	110	.0126	
6	110	.0126	
7	134	.0089	
8	135	.0084	
9	136	.0084	
10	149	.0073	
11	148	.0079	
12	150	.0079	
13	172	.0100	
14	171–176	.0105	
15	170	.0100	

TABLE NO. 6—Continued.

Load on bearing, 133.4 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	78	.0192	Temperature of room, 64 deg.
2	81	.0180	
3	83	.0184	
4	111	.0121	
5	111	.0124	
6	112	.0112	
7	100	.0130	
8	102	.0126	
9	103	.0126	
10	125	.0101	
11	125–133	.0095	
12	128	.0106	
13	152	.0087	
14	152–157	.0090	
15	148	.0074	
16	165	.0070	
17	172	.0076	
18	171	.0087	

Load on bearing, 153.8 lbs. per sq. in. Surface speed of journal, 370 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	63	.0226	Temperature of room, 64 deg.
2	68	.0203	
3	70	.0192	
4	75	.0180	
5	78	.0172	
6	79	.0168	
7	96	.0137	
8	96	.0117	
9	96	.0129	
10	120	.0082	
11	120	.0078	
12	119	.0080	
13	135	.0060	
14	137	.0062	
15	135	.0068	
16	167	.0072	
17	160	.0068	
18	158	.0064	

TABLE NO. 7.

X GREASE, NO. 3. DENSITY.

Series B. Loads of 53.5 to 153.8 lbs. per sq. inch. See figs. 17 and 18.
Diameter of journal, 1 1-4″; length, 2″.
Grease cup with spring actuated plunger.

Load on bearing, 53.5 lbs. per sq. in. Surface speed of journal, 405 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	76	.0414	Room temperature, 72 deg.
2	80	.0342	
3	81	.0358	
4	82	.0352	
5	92–96	.0268	
6	94–97	.0246	
7	95	.0218	
8	110–114	.0190	
9	111	.0213	
10	111	.0213	
11	124	.0173	
12	125	.0185	
13	126	.0168	
14	141	.0145	
15	141	.0134	
16	140	.0151	
17	154	.0134	
18	156	.0112	
19	157	.0117	
20	170	.0101	
21	168	.0106	
22	170	.0140	

Load on bearing, 74 lbs. per sq. in. Surface speed of journal, 395 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	78	.0276	
2	79	.0252	
3	80	.0244	
4	95	.0187	
5	96	.0199	
6	97	.0211	
7	120	.0122	
8	119–122	.0134	
9	120	.0097	
10	135	.0081	
11	134	.0069	
12	135	.0065	
13	152	.0049	
14	155	.0049	
15	155	.0040	
16	168–171	.0041	
17	171	.0053	
18	171–189	.0057	

Load on bearing, 94.1 lbs. per sq. in. Surface speed of journal, 380 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	61	.0312	Room temperature, 67 deg.
2	69	.0262	
3	73	.0242	
4	75	.0204	
5	76	.0198	
6	96	.0131	
7	95	.0121	
8	95	.0124	
9	110	.0086	
10	111	.0115	
11	100–110	.0127	
12	124	.0079	
13	126	.0064	
14	125	.0067	
15	143	.0048	
16	141	.0054	
17	139	.0054	
18	161	.0045	
19	160	.0042	
20	160	.0048	

Load on bearing, 114.2 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0212	Room temperature, 67 deg.
2	77	.0173	
3	78	.0171	
4	79	.0171	
5	96	.0145	
6	96	.0137	
7	96	.0123	
8	108–111	.0123	
9	112	.0094	
10	110	.0094	
11	127	.0073	
12	125	.0068	
13	125	.0068	
14	140	.0059	
15	140	.0052	
16	140	.0052	
17	159	.0039	
18	161	.0037	
19	160	.0039	

TABLE NO. 7—Continued.

Load on bearing, 133.4 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	80	.0162	
2	83	.0119	
3	80	.0126	
4	97	.0090	
5	96	.0104	
6	96	.0099	
7	114	.0061	
8	113	.0052	
9	113	.0052	
10	131	.0049	
11	130	.0043	
12	132	.0038	
13	144	.0038	
14	146	.0034	
15	145	.0034	
16	158–162	.0038	
17	161	.0043	
18	161	.0043	

Load on bearing, 153.8 lbs. per sq. in. Surface speed of journal, 390 feet per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	56	.0285	Room temperature, 62 deg.
2	60	.0223	
3	64	.0156	
4	67	.0148	
5	71	.0145	
6	77	.0121	
7	93	.0098	
8	94	.0103	
9	95	.0090	
10	108	.0074	
11	108	.0070	
12	110	.0070	
13	123	.0060	
14	125	.0055	
15	124	.0059	
16	139	.0049	
17	140	.0047	
18	141	.0041	
19	158	.0035	
20	160	.0037	
21	160	.0037	

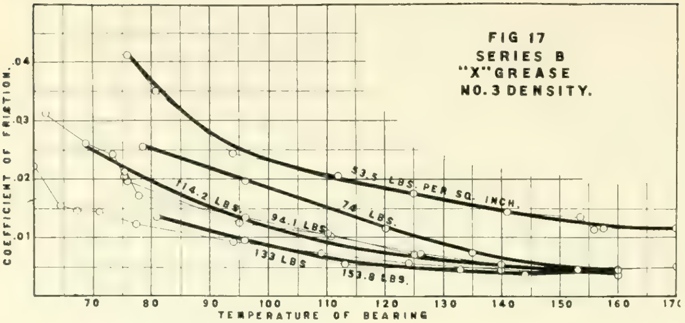
FIG 17
SERIES B
"X" GREASE
NO. 3 DENSITY.

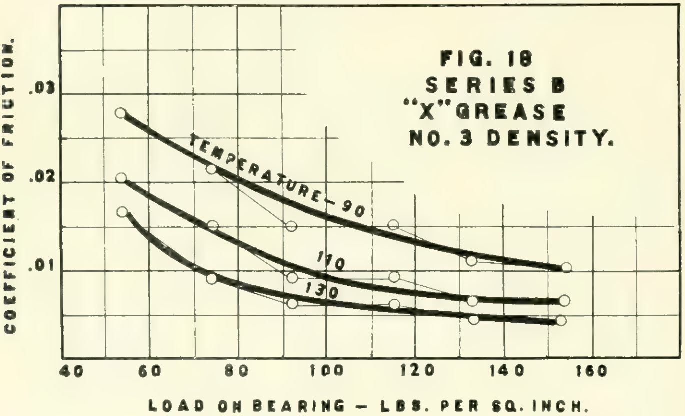
FIG. 18
SERIES B
"X" GREASE
NO. 3 DENSITY.

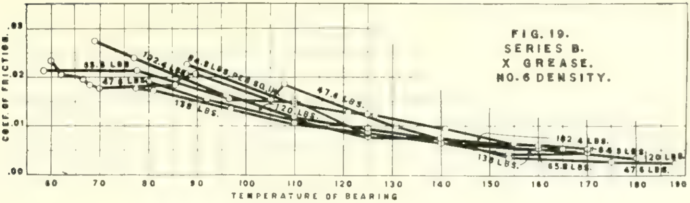
FIG. 19.
SERIES B.
X GREASE.
NO. 6 DENSITY.

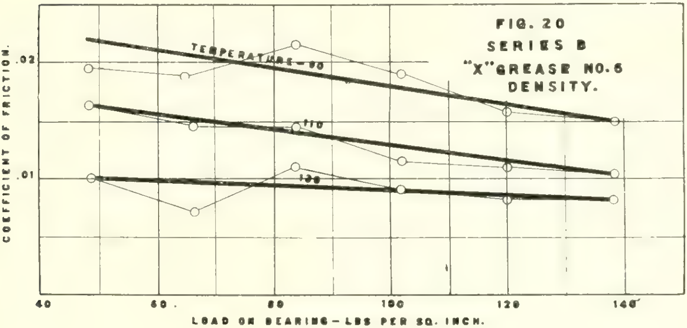
FIG. 20
SERIES B
"X" GREASE NO. 6
DENSITY.

TABLE NO. 8.

X GREASE, NO. 6 DENSITY.

Series B. Loads of 47.6 to 138 pounds per sq. inch. See figs. 19 and 20.
Diameter of journal, 1 1-4″; length, 2 1-4″.
Grease was semi-liquid, fed by gravity to the bearing.

Load on bearing, 47.6 lbs. per sq. in. Surface speed of journal, 395 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	60	.0235	Room temperature, 62 deg.
2	62	.0207	Bearing was new when this test was started, and did not run very smoothly. A rapid feed of oil was necessary.
3	66	.0196	
4	68	.0185	
5	70	.0179	
6	85	.0185	
7	87	.0207	
8	89	.0207	
9	115–118	.0185	
10	115	.0157	
11	114	.0146	
12	115	.0100	
13	132	.0123	
14	131	.0089	
15	132	.0084	
16	155	.0039	
17	154	.0039	
18	155	.0034	
19	175	.0028	
20	177	.0033	
21	175	.0028	
22	187	.0022	
23	188	.0028	
24	190	.0022	

Load on bearing, 65.8 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0203	Room temperature, 53 degrees.
2	49	.0260	
3	58	.0212	
4	75–78	.0252	
5	80	.0236	
6	78	.0195	
7	95–100	.0163	
8	97	.0138	
9	94	.0163	
10	110	.0122	
11	110	.0106	
12	122–126	.0089	
13	125	.0081	
14	125	.0073	
15	138–144	.0057	
16	142	.0073	
17	140	.0065	
18	154	.0048	
19	154	.0049	
20	154	.0041	

TABLE NO. 8—Continued.

Load on bearing, 84.3 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	88	.0255	After the preceding run, the journal was run about three hours to wear the bearing surfaces smooth. It now runs much better.
2	89	.0204	
3	86	.0223	
4	110	.0151	
5	111	.0145	
6	110	.0150	
7	127	.0121	
8	125	.0124	
9	121	.0127	
10	142–146	.0101	
11	140	.0095	
12	140	.0082	
13	155	.0063	
14	155	.0069	
15	155	.0063	
16	168–172	.0057	
17	173	.0050	
18	171	.0054	

Load on bearing, 102.4 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	70	.0276	
2	75	.0239	
3	77	.0228	
4	78	.0223	
5	96	.0161	
6	109	.0109	
7	110	.0130	
8	110	.0119	
9	122	.0091	
10	126	.0096	
11	125	.0093	
12	140	.0083	
13	160	.0060	
14	160	.0070	
15	162	.0052	

Load on bearing, 120 lbs. per sq. in. Surface speed of journal, 395 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	80	.0191	
2	81	.0186	
3	82	.0193	
4	90	.0160	
5	93	.0142	
6	93	.0155	
7	110	.0106	
8	109	.0120	
9	110	.0109	
10	125	.0071	
11	124	.0084	
12	127	.0084	
13	142	.0080	
14	141	.0071	
15	140	.0071	
16	159	.0062	
17	160	.0053	
18	163	.0049	
19	176	.0035	
20	176–179	.0038	
21	181	.0033	

Load on bearing, 138 lbs. per sq. in. Surface speed of journal, 390 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	77	.0177	
2	80	.0171	
3	83	.0173	
4	96	.0131	
5	98	.0130	
6	108–112	.0108	
7	109	.0100	
8	126	.0081	
9	138–143	.0069	
10	141	.0065	
11	158–165	.0054	

TABLE NO. 9.

Y GREASE, NO. 5 DENSITY.

Series B. Loads of 53.7 to 154.4 pounds per sq. inch. See figs. 21 and 22.
Diameter of journal, 1 1-4″; length, 2″.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 53.7 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	90	.0378	Compression grease cup used. Observations taken immediately after feeding grease to bearing.
2	90	.0280	
3	95	.0290	
4	100	.0266	
5	104	.0266	
6	108	.0234	
7	82	.0234	
8	84	.0234	
9	95	.0256	
10	100	.0234	
11	104	.0234	
12	108	.0244	
Second test at load of 53.7 lbs. per sq. inch. Surface speed of journal, 395 ft. per min.			
1	138	.0240	Compression grease cup used. Observations were made immediately after feeding grease.
2	151	.0240	
3	153	.0267	
4	140–158	.0246	
5	156	.0267	
6	157	.0252	
7	173	.0272	
8	190	.0278	
Load on bearing, 74.1 lbs. per sq. in. Surface speed of journal, 410 ft. per min.			
1	77	.0244	Compression grease cup used.
2	80	.0244	
3	82	.0210	
4	83	.0396	Observation after running ten minutes without feeding grease to bearing.
5	83	.0201	
6	82	.0210	
Second test at load of 74.1 lbs. per sq. in. Surface speed of journal, 410 ft. per min.			
1	110	.0146	Compression grease cup used.
2	116	.0162	Reading taken after running three minutes without feeding grease to bearing
3	118	.0146	Read immediately after feeding grease.
4	120	.0162	Three minutes without feeding grease.
5	118	.0146	Read after feeding grease.
6	160	.0220	
7	164	.0236	Read two minutes after feeding grease.
8	160	.0220	Read after feeding grease.
9	183	.0260	Read after feeding grease.
10	190	.0260	
Load on bearing, 94.4 lbs. per sq. in. Surface speed of journal, 405 ft. per min.			
1	83	.0170	Compression grease cup used.
2	84	.0345	Read three minutes after feeding grease.
3	84	.0170	Read after feeding grease.
4	84	.0308	Four minutes after feeding grease.
5	84	.0166	Read after feeding grease.
6	86	.0153	Read after feeding grease.
7	92	.0173	Read after feeding grease.
8	94	.0198	Read after feeding grease.
9	96	.0186	Read after feeding grease.
10	118	.0152	Read after feeding grease.
11	128	.0192	Read after feeding grease.
12	143	.0243	Read after feeding grease
13	157	.0204	Read after feeding grease

TABLE NO. 9—Continued.

Second test at load of 94.4 lbs. per sq. in. Grease cup with spring loaded plunger used. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	73	.0228	
2	77	.0228	
3	80	.0224	
4	84	.0217	
5	88	.0200	
6	92	.0196	

Third test at load of 94.4 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	61	.040	Spring grease cup with constant feed.
2	70	.0345	
3	79	.0330	
4	84	.0256	Forced grease by hand
5	100	.0225	
6	109	.0192	
7–8	113	.0170	Forced grease by hand.
8	127	.0150	
9	145	.0142	
10	148–154	.0145	
11	143	0154	

Load on bearing, 114.4 lbs per sq. in. Surface speed of journal, 380 to 425 ft. per min

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	88	.0325	Spring grease cup used.
2	89	.0300	
3	94	.0280	Forced grease in by hand before reading.
4	86	.0168	
5	89	.0152	
6	98	.0155	
7	98	.0178	
8	102	.0126	Forced grease in by hand before reading
9	104	.0147	
10	106	0180	
11	136–145	0149	

Second test at load of 114.4 lbs. per sq. in Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	79	.024	Spring grease cup used.
2	81	.024	
3	85	.0260	
4	88	.0190	
5	88	.0152	
6	88	.0188	
7	84	.0175	

Load on bearing, 133.4 lbs per sq in. Surface speed of journal, 408 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	78	.0175	Spring grease cup used.
2	98	.0140	
3	108	.0133	
4	112	.0173	
5	136	.0144	
6	136	.0150	
7	129–132	.0130	
8	128–140	.0085	
9	152	.0079	

Second test at load of 133.4 lbs. per sq. in Surface speed of journal, 408 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	69	.0199	
2	74	.0163	
3	80–85	.0158	
4	87	.0164	
5	88–98	.0159	
6	96	.0160	

Load on bearing, 154 lbs. per sq. in. Surface speed of journal, 425 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	80–85	.0181	Spring grease cup used
2	85	.0144	
3	90	.0128	
4	92	0133	

TABLE NO. 9—Continued.

Second test at load of 154 lbs. per sq. in Surface speed of journal, 410 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	94	.0125	Spring grease cup used.
2	106	.0113	
3	117	.0094	
4	162–168	.0095	
5	137	.0098	
6	124	.0066	
7	122	.0084	
8	143	.0112	
9	140	.0109	

Third test at load of 154 lbs. per sq. in. Surface speed of journal, 420 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	91	.0122	
2	89	.0137	
3	98–106	.0094	
4	118–127	.0094	
5	147	.0086	
6	152	.0094	

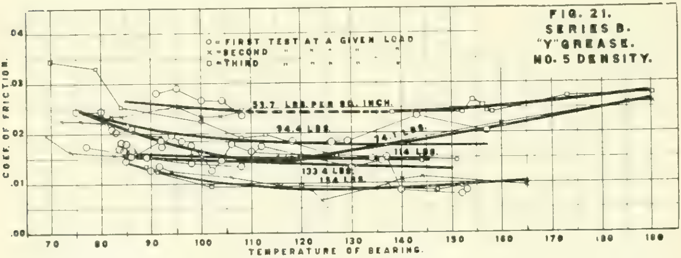

FIG. 21.
SERIES B.
"Y" GREASE.
NO. 5 DENSITY.

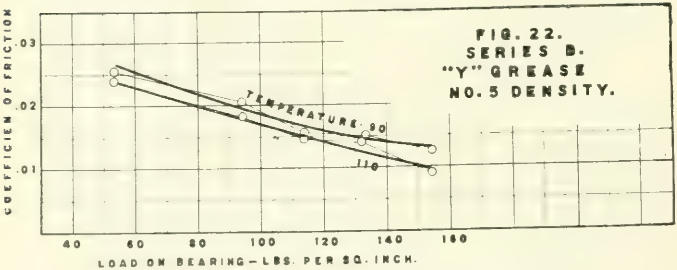

FIG. 22.
SERIES B.
"Y" GREASE
NO. 5 DENSITY.

TABLE NO. 10.

Y GREASE, NO. 3 DENSITY.

Series B. Loads of 53.7 to 154.4 pounds per sq. inch. See figs. 23 and 24. Diameter of journal, 1 1-4″; length, 2″.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks	Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 53.7 lbs. per sq. in. Surface speed of journal, 350 ft. per min.				Load on bearing, 74.2 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	75	.0236	Spring grease cup used.	1	70	.0244	
2	79	.0258		2	72	.0220	
3	108–116	.0156		3	76	.0220	
4	120	.0145		4	100–119	.0145	
5	125–140	.0145		5	90–100	.0154	
6	149	.0134		6	86	.0179	
7	130–149	.0179		7	99	.0170	
8	100–108	.0178		8	130–140	.0138	
9	91	.0190		9	134	.0133	
10	85	.0200		10	130	.0122	
11	83	.0275		11	125	.0110	
12	82	.0200		12	107	.0093	
				13	97	.0169	
				14	96	[illegible]	

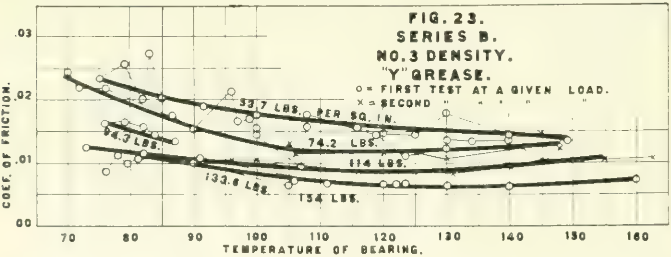
FIG. 23.
SERIES B.
NO. 3 DENSITY.
"Y" GREASE.

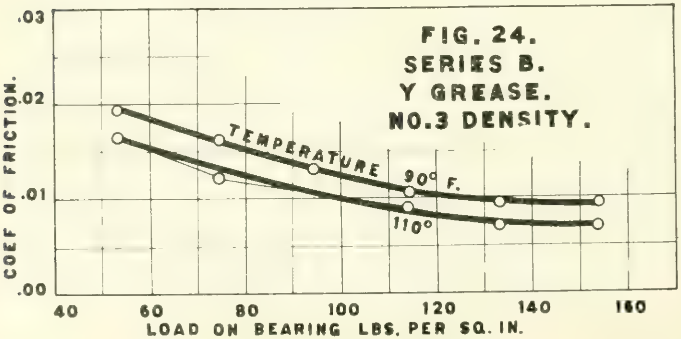
FIG. 24.
SERIES B.
Y GREASE.
NO. 3 DENSITY.

TABLE NO. 10—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks

Second test at load of 74.2 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

1	106	.0114	
2	105	.0130	
3	120–125	.0117	
4	130	.0106	
5	142–148	.0121	
6	148	.0130	
7	144	.0148	

Load on bearing, 94.3 lbs. per sq. in. Surface speed of journal, 425 ft. per min.

1	76	.0162	
2	79	.0166	
3	82	.0159	
4	84	.0143	
5	87	.0134	

Load on bearing, 114.4 lbs. per sq. in. Surface speed of journal, 425 ft. per min.

1	77	.0089	
2	78	.0115	
3	80	.0100	
4	82	.0113	
5	84	.0110	

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks

Second test at load of 114.4 lbs. per sq. in. Surface speed of journal, 425 ft. per min.

1	61	.0198	
2	98	.0105	
3	90	.0102	
4	116	.0087	
5	123	.0087	
6	134	.0082	
7	142	.0092	
8	145	.0105	
9	153	.0105	
10	163	.0107	

Load on bearing, 133.6 lbs. per sq. in. Surface speed of journal, 375 ft. per min.

1	81	.0148	
2	81	.0108	
3	91	.0108	
4	111	.0069	
5	123	.0068	
6	122	.0081	
7	122	.0067	

Load on bearing, 154.4 lbs. per sq. in. Surface speed of journal, 410 ft. per min.

1	73	.0123	
2	90	.0100	
3	100–106	.0072	
4	105	.0064	
5	112–120	.0065	
6	130	.0061	
7	140–145	.0061	
8	158–161	.0072	

TABLE NO. 11.

Y GREASE. NO. 2 DENSITY.

Series B. Loads of 53.5 to 154 pounds per sq. inch. See figs. 25 and 26.
Diameter of bearing, 1 1-4″; length, 2″.
Compression grease cup used.

Load on bearing, 53.5 lbs. per sq. in. Surface speed of journal, 420 to 450 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	69	.0585	Room temperature, 70 degrees.
2	78	.0540	Reversed motor.
3	90	.0720	Grease fed after observation.
4	96	.0540	
5	96	.0338	Motor reversed.
6	96	.0372	
7	. .	.0372	Motor reversed.
8	. .	.0327	Motor reversed.
9	100	.0360	
10	100	.0360	Motor reversed.
11	100	.036	Motor reversed.
12	102	.0314	
13	102	.0314	Motor reversed.
14	104	.0566	Grease fed after observation.
15	. . .	.0250	
16	106	.027	
17	120	.0360	
18	121	.0405	Motor reversed.
19	121	.0400	Grease fed after observation.
20	118	.0282	
21	118	.0286	Motor reversed.
22	126	.0305	

Load on bearing, 73.5 lbs. per sq. in. Surface speed of journal, 375 to 420 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	62	.0433	Room temperature, 64 deg.
2	68	.0417	
3	70	.0417	Motor reversed.
4	76	.0400	
5	81	.0400	
6	84	.0360	Motor reversed.
7	86	.0320	
8	88	.0320	Motor reversed.
9	92	.0320	
10	96	.0390	Unsteady. Grease fed after observation.
11	. .	.0307	
12	96	.0307	
13	98	.0257	
14	98	.0252	Motor reversed.
15	116	.0237	Ran fifty minutes without feeding grease.
16	. . .	.0250	
17	108	.0250	

Load on bearing, 93.5 lbs. per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0303	Room temperature, 68 deg.
2	80	.0303	
3	88	.0253	Motor reversed.
4	89	.0253	
5	90	.0253	Motor reversed.
6	93	.0250	
7	. .	.0250	Motor reversed.
8	99	.0233	

Load on bearing, 114 lbs. per sq. in. Surface speed of journal, 405 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	59	.0336	Room temperature, 61 deg.
2	64	.0336	Motor reversed.
3	70	.0331	
4	73	.0331	Motor reversed.
5	77	.0291	Grease fed at 5 minutes.
6	80	.0291	Motor reversed.
7	82	.0218	
8	. .	.0218	Motor reversed.
9	85	.0185	
10	87	.0185	Motor reversed.
11	92	.0185	Motor reversed at every observation for the remainder of this run.

TABLE NO. 11—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
12	93	.0178	
13	96	.0178	
14	98	.0165	Ran 125 minutes without feeding any additional grease.
15	109	.0189	
16	107	.0160	
17	106	.0160	
18	104	.0160	

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Load on bearing, 133.5 lbs. per sq. in. Surface speed of journal, 380 ft. per min.			
1	67	.0238	Room temperature, 66 deg.
2	72	.0238	Motor was reversed after each observation.
3	77	.0189	
4	82	.0180	
5	92	.0166	
6	95	.0152	
Load on bearing, 154 lbs. per sq. in. Surface speed of journal, 400 ft. per min.			
1	72	.0186	Motor reversed after each observation.
2	78	.0186	
3	90	.0151	
4	104	.0162	
5	...	.0108	
6	...	.0093	
7	106	.0085	
8	110	.0104	

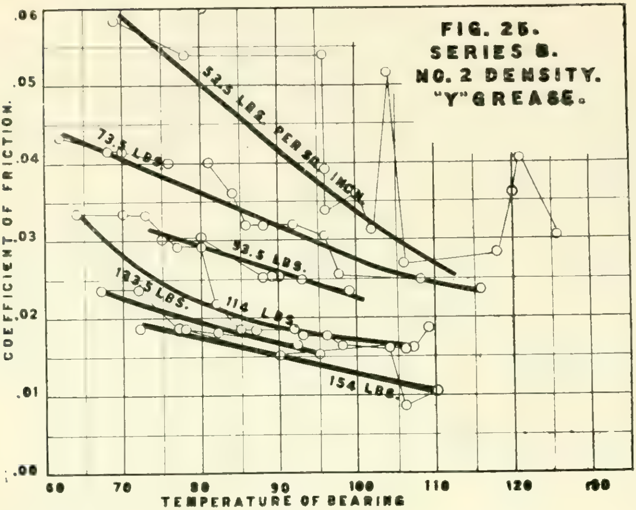

FIG. 25.
SERIES B.
NO. 2 DENSITY.
"Y" GREASE.

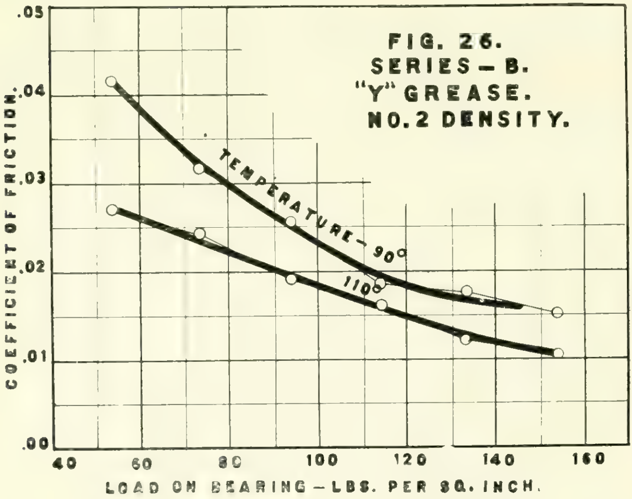

FIG. 26.
SERIES — B.
"Y" GREASE.
NO. 2 DENSITY.

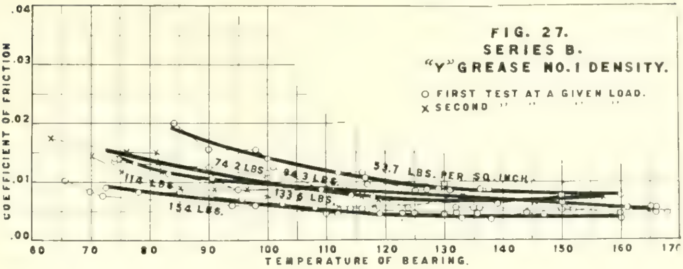

FIG. 27.
SERIES B.
"Y" GREASE NO. 1 DENSITY.

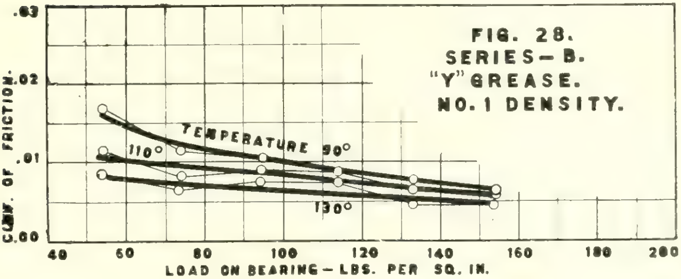

FIG. 28.
SERIES—B.
"Y" GREASE.
NO. 1 DENSITY.

TABLE. NO. 12.

Y GREASE, NO. 1 DENSITY.

Series B. Loads of 53.7 to 154 pounds per sq. inch. See figs. 27 and 28. Diameter of bearing, 1 1-4″; length, 2 ′.

Load on bearing, 53.7 lbs. per sq. in. Surface speed of journal, 410 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	79	.0490	Spring feed grease cup used.
2	86	.0390	
3	84	.0200	
4	90–98	.0156	
5	100	.0140	
6	114	.0117	
7	117	.0107	
8	138	.0089	
9	129–136	.0089	
10	125	.0084	
11	160	.0078	

Load on bearing, 74.2 lbs. per sq. in. Surface speed of journal, 395 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	74	.0263	
2	77	.0132	Increased feed of grease before reading.
3	90–101	.0126	
4	100	.0114	
5	100	.0106	
6	124	.0057	
7	139	.0089	
8	136	.0089	
9	118	.0073	
10	109	.0088	

Second test at 74.2 lbs. per sq. in. Surface speed of journal, 345 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	63	.0179	
2	76–81	.0150	
3	82	.0118	
4	100–116	.0074	
5	112–118	.0059	
6	152–157	.0073	

Load on bearing, 94.3 lbs. per sq. in. Surface speed of journal, 410 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	75	.0140	
2	83	.0114	
3	90	.0108	
4	95	.0086	
5	127	.0095	
6	127	.0086	
7	131	.0086	
8	139	.0061	
9	152–165	.0050	
10	163	.0057	
11	117–130	.0096	
12	131	.0086	
13	141	.0080	
14	150	.0076	At temperature of 150 degrees lubrication is uncertain. The oil film could be maintained only by rapid feeding of grease.
15	161	.0089	
16	150	.0064	

Load on bearing, 114.4 lbs per sq. in. Surface speed of journal, 400 ft. per min.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
1	77	.0184	
2	80	.0184	
3	94	.0173	
4	102	.0168	
5	115–120	.0108	
6	119	.0084	
7	115	.0071	
8	125–133	.0087	
9	138	.0084	Increased feed of grease.
10	130	.0068	
11	154–163	.0060	
12	162	.0065	
13	150–157	.0060	
14	142	.0068	

TABLE NO. 12—Continued.

Number	Bearing Temperature, Degrees F.	Coefficient of Friction	Remarks
Second test at load of 114.4 lbs. per sq. in. Surface speed of journal, 380 ft. per min.			
1	62	.0172	
2	70	.0142	
3	75	.0088	Increased feed of grease.
4	85–91	.0089	
5	96	.0089	
6	109–133	.0084	
7	119	.0068	
8	145	.0063	
9	140	.0084	
10	130–135	.0096	
Load on bearing, 133.4 lbs. per sq. in. Surface speed of journal, 380 ft. per min.			
1	72	.0090	
2	74	.0140	
3	78–85	.0083	
4	108	.0058	
5	119–123	.0045	
6	125–130	.0045	
7	135	.0047	
8	145	.0044	
9	143	.0047	
10	134–138	.0038	
11	160	.0038	
Load on bearing, 153.8 lbs. per sq. in. Surface speed of journal, 390 ft. per min.			
1	66	.0101	
2	70	.0086	
3	72	.0078	
4	93	.0060	
5	97	.0064	
6	111	.0047	
7	115	.0055	
8	125–132	.0047	
9	135	.0057	
10	152	.0051	
11	160–168	.0045	
12	136	.0055	

TABLE NO. 13.

GREASE, NO. 1.

Series C. Comparison of oil hole lubrication with compression grease cup, hand operated. Load on bearing, 114 pounds per sq. inch.

To test for oil hole lubrication, a measured quantity of grease was placed in the holes. Successive runs were then made without further addition of grease until the lubrication failed.

Oil hole lubrication See fig. 29, curves 1a, 2a, 3a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a.			
0	79	3	.092
10	145	69	.092
20	133	57	.033
30	145	69	.040
40	145	69	.040
50	142	66	.035
60	142	66	.035
70	150	74	.025
80	155	79	.025
90	142	66	.013
Second run, curves 2a.			
0	75	11	.107
10	..	..	.107
20	189	125	.092
30	187	123	.092
40	177	116	.074
50	176	115	.027
60	145	84	.027
85	137	66	.027
115	120	58	.027
140	134	74	.027
150	135	75	.027
175	136	76	.027
190	133	73	.018
Third run, curves 3a.			
0	70	1	.062
5	85	16	.062
10	117	48	.062
20	...	..	.062
30	123	53	.032
40	139	69	.032
50	...	..	.032
60	140	68	.032
90	133	61	.032
110	135	63	.025
120	136	62	.025
140	181	107	.035
180	158	82	.025
220	160	84	.032
240	168	92	.087

Lubrication failed at this point.

Grease cup lubrication. See fig. 29, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	77	0	.030
3	88	11	.030
10	97	20	.025
20	113	36	.021
85	131	54	.017
120	145	68	.017
180	142	65	.022
180	142	65	.015
(The last reading was observed after forcing in grease.)			
Second run, curves 2b.			
0	85	2	.035
3	93	9	.035
6	100	17	.024
22	124	41	.022
22	124	41	.015
(The last reading was observed after forcing in grease.)			
30	122	39	.020
40	127	44	.020
65	141	58	.016
90	150	67	.013
100	142	59	.016
115	150	67	.014
116	...	...	.017

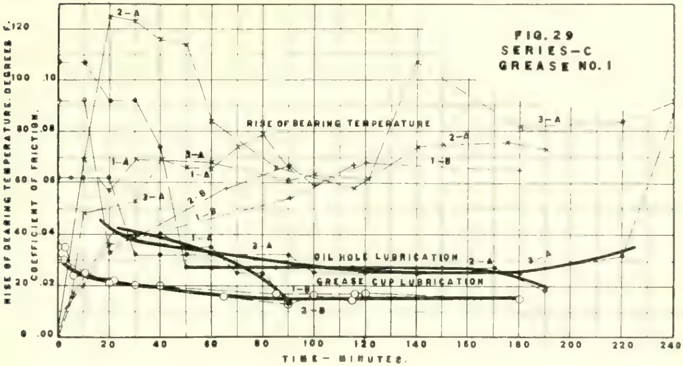
FIG. 29
SERIES—C
GREASE NO. 1

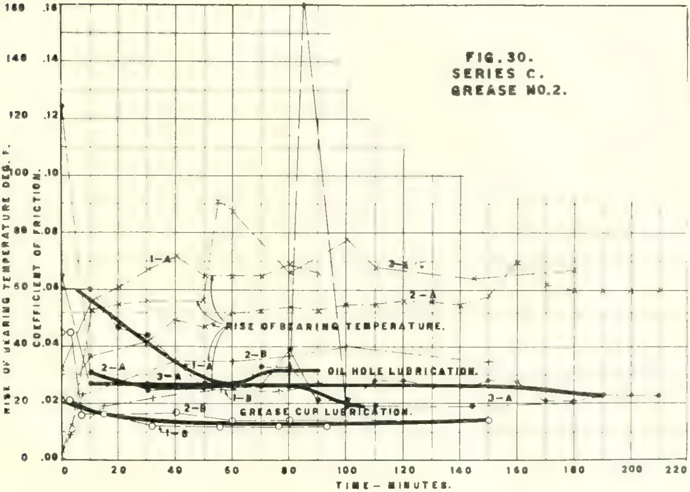
FIG. 30.
SERIES C.
GREASE NO. 2.

TABLE NO. 14.

TEST SERIES C. GREASE NO. 2.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 30, curves 1a, 2a, 3a.

Time, Minutes	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a.			
0	102	32	.060
10	126	56	.060
20	131	61	.047
30	137	67	.044
40	142	72	.034
50	135	65	.026
60	135	65	.027
70	135	65	.026
80	139	69	.039
90	136	66	.021
Second run, curves 2a.			
0	105	22	.124
10	120	37	.031
30	125	42	.025
40	133	50	.025
50	130	47	.026
60	135	52	.026
70	136	53	.033
80	137	54	.033
90	136	53	.021
100	138	55	.021
110	138	55	.028
120	139	56	.028
130	139	56	.025
140	138	55	.026
150	141	58	.028
160	153	70	.028
170	145	62	.021
180	143	60	.021
190	143	60	.023
200	143	60	.023
210	143	60	.023
Third run, curves 3a.			
0	65	0	.065
3	84	12	....
10	125	53	.027
20	127	55	.027
30	128	56	.027
50	128	56	.027
60	160	88	.026
80	139	66	.026
85	...	..	.101
100	151	78	.019
110	141	68	.019
145	137	64	.019
180	140	67	.020

Grease cup lubrication. See fig 30, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F	Coefficient of Friction.
First run, curves 1b			
0	90	1	.021
3	98	9	.021
15	108	19	.016
31	110	21	.012
56	115	25	.012
76	116	26	.012
93	119	29	.012
Second run, curves 2b.			
0	75	3	.045
3	83	12	.045
17	94	23	.016
40	107	35	.017
60	108	35	.014
80	110	37	.014
100	113	40	.014
150	111	35	.014

TABLE NO. 15.

TEST SERIES C. GREASE NO. 3.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 31, curves 1a, 2a, 3a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a. Ran 2½ minutes before first observation.			
0	137	62	.046
7.5	160	85	.046
10	167	92	.082
15	169	94	.082
20	169	94	.029
25	162	87	.029
30	163	88	.015
35	158	83	.015
40	159	84	.0126
Second run, curves 2a.			
0	108	36	.063
5	136	64	.063
10	138	66	.063
15	138	66	.063
20	138	66	.036
30	140	68	.036
40	148	76	.035
50	148	76	.035
60	153	81	.027
70	149	77	.027
80	170	97	.065
90	160	87	.035
Third run, curves 3a.			
0	88	16	.080
2.5	100	28	.080
5	112	40	.080
7.5	122	50	.080
15	127	55	.080
20	141	69	.077
30	150	78	.067
40	150	78	....
50	176	104	.043
60	180	108	.043
70	170	98	.027
80	181	108	.027
90	171	98	.072
100	175	102	.040
106	172	99	.040

Grease cup lubrication. See fig. 31, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction
First run, curves 1b.			
0	82	2	.033
5	95	15	.032
10	106	29	.033
20	116	36	.024
50	135	55	.017
65	145	65	.016
85	140	60	.020
100	140	60	.020
Second run, curves 2b.			
0	81	3	.039
10	110	32	.024
20	113	35	.022
60	146	68	.020

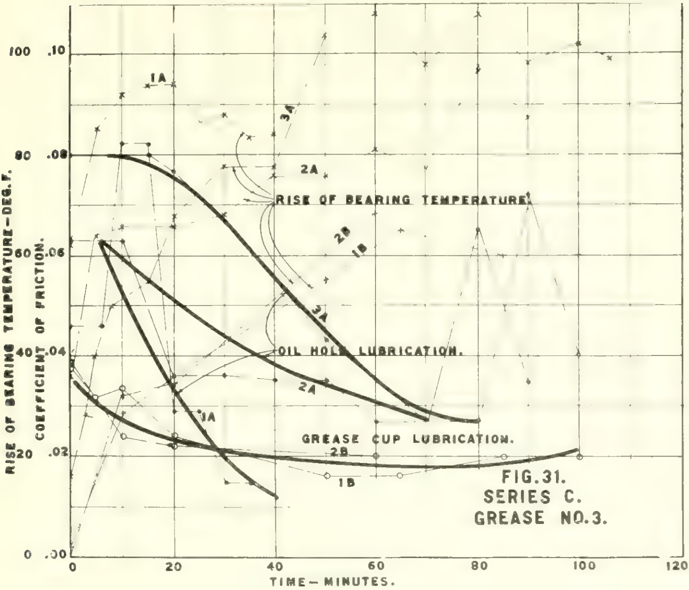

FIG. 31.
SERIES C.
GREASE NO. 3.

TABLE NO. 16.

TEST SERIES C, GREASE NO. 4.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 32, curves 1a, 2a.				Grease cup lubrication, see fig. 32, curves 1b, 2b.			
Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.	Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1a.				First run, curves 1b.			
0	147	172	.122	0	74	0	.078
3	164	104	.010	2	90	16	.078
5	180	120	.116	3	98	24	.078
10	169	108	.072	12	114	40	.074
15	166	105	.073	17	130	56	.063
20	168	108	.036	26	145	71	.059
30	154	94	.028	41	158	86	.050
40	145	85	.028	56	165	89	.059
60	143	82	.026	71	173	96	.047
70	154	93	.026	86	178	101	.054
				105	175	98	.044
Second run, curves 2a.							
0	76	0	.041	Second run, curves 2b.			
3	92	16	.041	0	86	5	.155
10	132	56	.066	5	118	37	.055
20	137	61	.037	10	133	51	.050
30	138	63	.038	20	148	67	.047
40	142	68	.030	30	170	89	.041
50	142	68	.030	45	163	81	.040
60	162	88	.026	60	173	91	.044
70	149	75	.026	62	173	91	.053
80	144	70	.026	65	...	..	.049
90	143	69	.026	80	186	104	.044
100	140	66	.024	110	180	98	.046
110	138	64	.024				
120	138	64	.072				
130	143	69	.102				
140	196	122	.102				

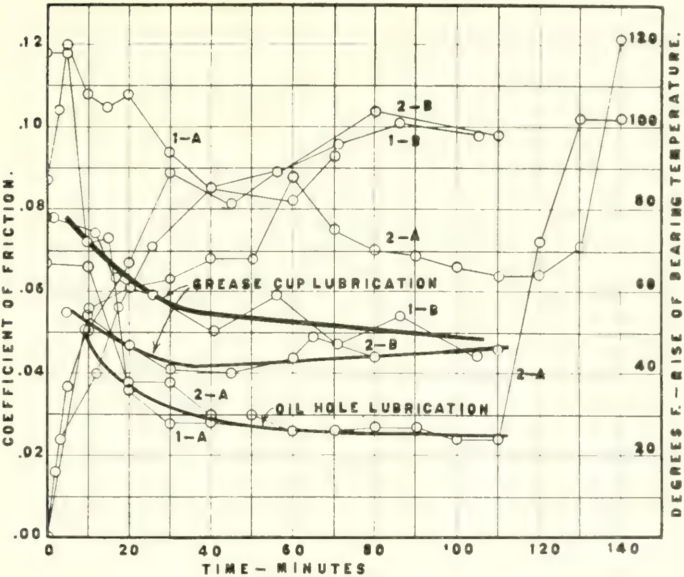

FIG. 32. SERIES C. GREASE NO. 4.

TABLE NO. 17.

TEST SERIES C, GREASE NO. 5.

Comparison of oil hole lubrication with compression grease cup, hand operated.

Load on the bearing, 114 pounds per sq. inch.

Oil hole lubrication. See fig. 33, curves a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
0	131	54	.074
2.5	134	57	.073
5	143	66	.073
7.5	145	68	.067
10	148	71	.038
12.5	160	83	.169
15	171	94	.136
17.5	176	99	.068
22.5	196	119	.191

This grease gave very poor lubrication.

Grease cup lubrication. See fig. 33, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	103	27	.071
2	109	33	.071
7	122	46	.069
15	146	70	.047
25	150	74	.034
35	146	70	.025
45	158	82	.037
55	160	84	.037
60	163	87	.045
Second run, curves 2b.			
0	93	18	.171
5	136	61	.099
10	142	67	.066
20	160	85	.046
35	167	92	.042

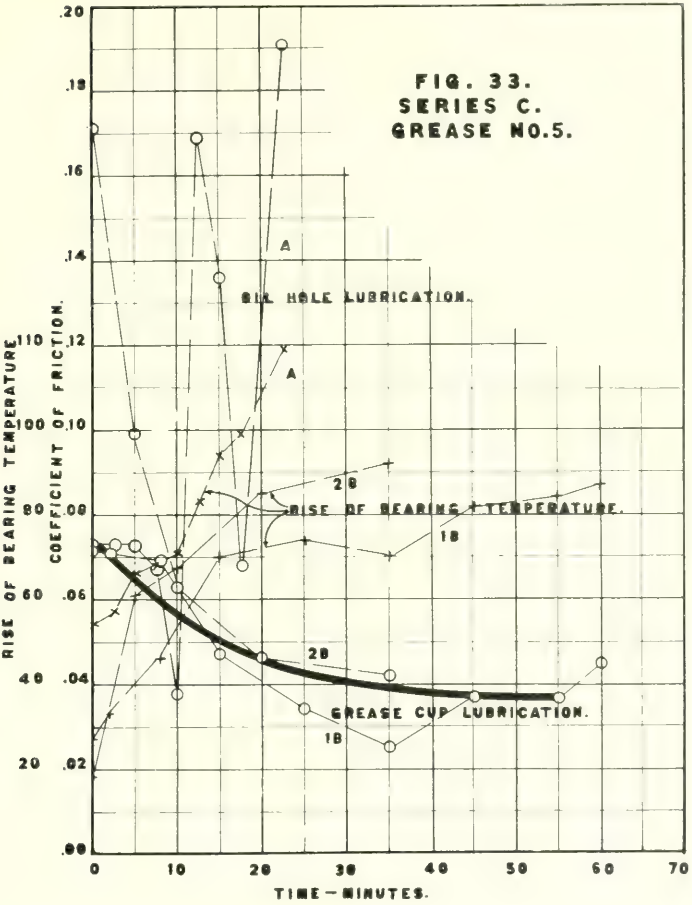
FIG. 33.
SERIES C.
GREASE NO.5.
OIL HOLE LUBRICATION.
GREASE CUP LUBRICATION.
RISE OF BEARING TEMPERATURE.
A
A
2B
2B
1B
1B
RISE OF BEARING TEMPERATURE
COEFFICIENT OF FRICTION.
TIME—MINUTES.
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
.00
110
100
80
60
40
20
0
10
20
30
40
50
60
70

TABLE NO. 18.

TEST SERIES C, GREASE NO. 6.

Oil hole lubrication. See fig. 34, curves 1a.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
0	114	34	.084
3	140	60	.067
5	151	71	.033
8	166	86	.117
13	178	98	.124
18	190	110	.091
23	200	120	.108

Lubrication failed because grease would not flow into the bearing.

Grease cup lubrication. See fig. 34, curves 1b, 2b.

Time, Minutes.	Bearing Temperature, F.	Elevation of Temperature, F.	Coefficient of Friction.
First run, curves 1b.			
0	84	0	.064
2	98	14	.064
5	114	30	.044
10	125	41	.051
14	122	38	.052
34	136	52	.032
40	137	53	.029
50	135	51	.034
60	153	69	.034
Second run, curves 2b.			
0	80	0	.080
2	90	8	.080
5	110	28	.030
10	124	42	.042.
20	134	52	.041
30	136	54	.032
60	142	59	.031
80	143	60	.030

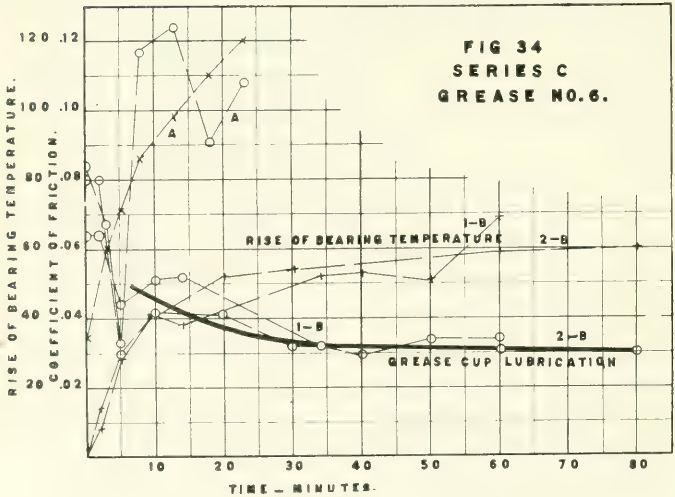
FIG 34
SERIES C
GREASE NO. 6.

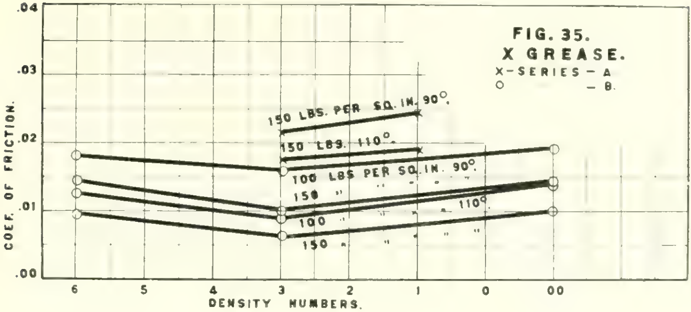

FIG. 35.
X GREASE.

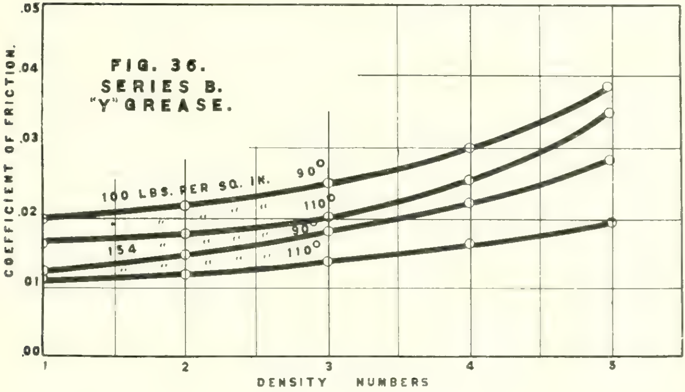

FIG. 36.
SERIES B.
"Y" GREASE.

An effort was made to determine the relation between the speed of journal and the coefficient of friction. In his tests upon lubricating oils, Beauchamp Tower showed that for a given oil tested at a constant temperature, the coefficient of friction where there was perfect lubrication varied directly as the square root of the surface speed of the journals and inversely as the pressure per square inch of projected area. That is;

$$\phi = K \sqrt{\frac{S}{w}}$$

S = surface speed of journal, feet per minute.

w = load on bearing, pounds per square inch of projected area.

K = a coefficient having different values for different lubricants, and for the same lubricant at different temperatures. From the observed values of **S, w,** and ϕ, in the tests of series A and B, the values of **K** were computed by substituting in the above equation, and were plotted against the corresponding temperature of the bearing. Figs. 37 and 38 show the results of these plots for the X and Y greases respectively. Greases of different densities and series are distinguished by different forms of mark, so that the table from which each point came may be identified. Curves are drawn bounding the areas above and below, and representing the extreme values of **K**. These curves are designated for convenience or reference, the upper curves, AB; the lower ones, CD. It will be noticed

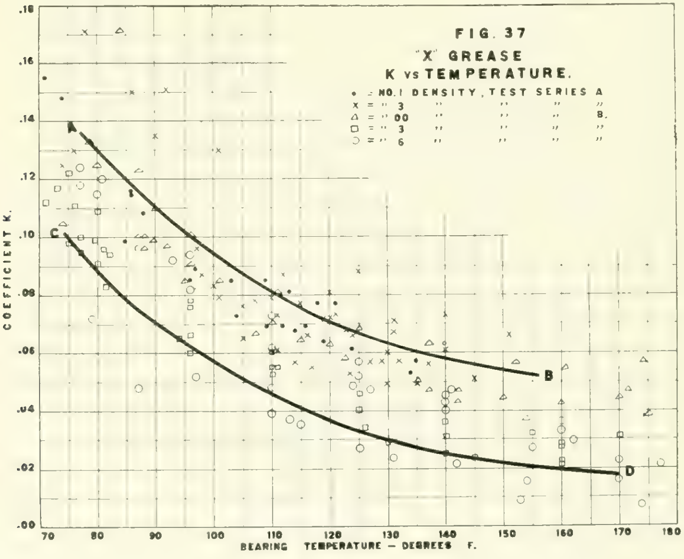
FIG. 37
"X" GREASE
K vs TEMPERATURE.

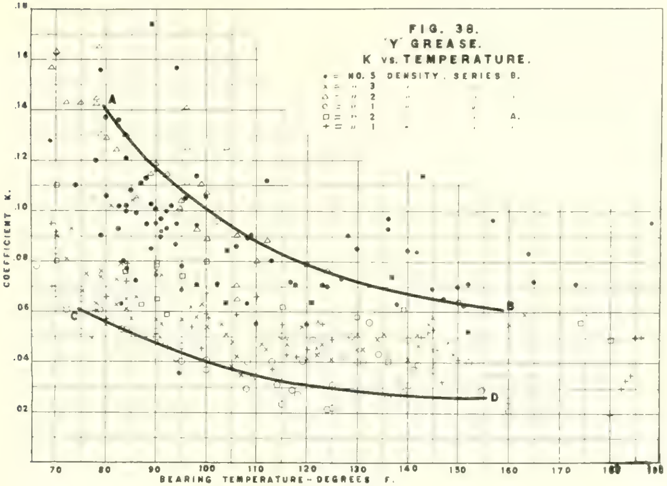

FIG. 38.
'Y' GREASE.
K vs. TEMPERATURE.

that the plots for the denser greases, in general, lie towards the upper curves CD; and the softer ones nearer the curves AB.

It was desired to find the relation between **K** and the bearing temperature, expressed in the form of an equation which might be of general application. For each of the four curves the points were replotted on logarithmic cross section paper, fig. 39. It appears from an inspection of the figure that **K** may be expressed in terms of the temperature by an equation of the form,

$$\mathbf{K} = \frac{\mathbf{M}}{t^n}$$

M = a constant.
t = bearing temperature, degrees F.
n = an exponent.

The following values of these numbers are found from the logarithmic plots.

X greases, curve, AB, $\mathbf{K} = \frac{78}{t^{1.16}}$

X greases, curve, CD, $\mathbf{K} = \frac{1370}{t^{2.11}}$

Y greases, curve, AB, $\mathbf{K} = \frac{49}{t^{1.34}}$.

Y greases, curve, CD, $\mathbf{K} = \frac{42}{t^{1.53}}$.

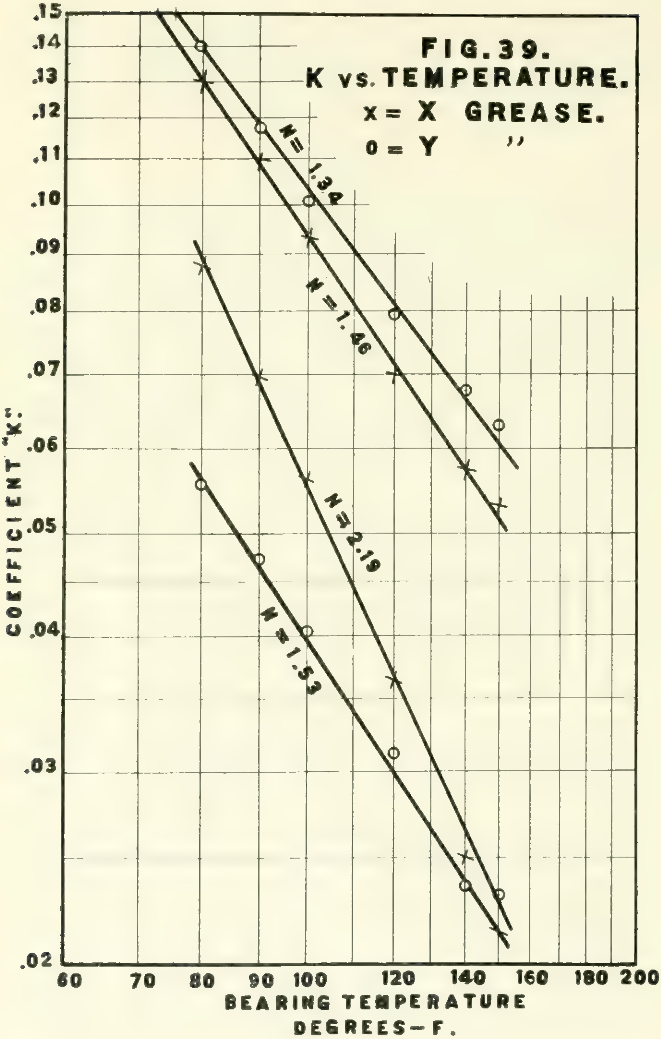
FIG. 39.
K vs. TEMPERATURE.
x = X GREASE.
0 = Y "
N = 1.34
N = 1.46
N = 2.19
N = 1.53
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
COEFFICIENT "K."
60
70
80
90
100
120
140
160
180
200
BEARING TEMPERATURE
DEGREES—F.

Lubricating oils are compared by means of certain physical tests; prominent among these is the test for viscosity. The viscosity of an oil is determined by means of a viscosimeter, several forms of which are in common use. A common form consists of a vessel to contain the oil, surrounded by a space which may be filled with water for the purpose of controlling the temperature. At the bottom of the vessel is a nozzle, through which a measured quantity of oil is permitted to flow. The viscosity is proportional to the time required for this quantity to flow through the nozzle.

It seemed to the writer that a similar scheme might be employed for the purpose of comparing greases as to their consistency, or density. As grease is a solid and therefore will not flow of itself, some compulsion must obviously be used to force the grease through the nozzle. After some preliminary experimentation, the apparatus shown in fig. 40 was constructed. This consisted of an ordinary grease cup supported upon an iron framework. A plunger was made to fit the cup closely. To insure perfect freedom of motion, the plunger was made slightly spherical. The plunger rod was carried through a guide, and supported weights placed upon its upper end. A scale graduated in twentieths of an inch was scribed on the rod, so that the time of descent over a measured distance might be noted. A nozzle of about ¼″ diameter was placed in the bottom of the cup.

Experiments with this instrument gave results that were, to the writer, decidedly surprising. It was found that the density of a given grease, as indicated by this means, is a very variable quality. Successive passages of the same grease gave constantly decreasing lengths of time for the same distance. The grease became softer and more fluid by the process of forcing it through the nozzle. This was particularly true of the harder greases. After several passages, the grease became oily in appearance. The change may be due to a more thorough mixing of the ingredients composing the grease.

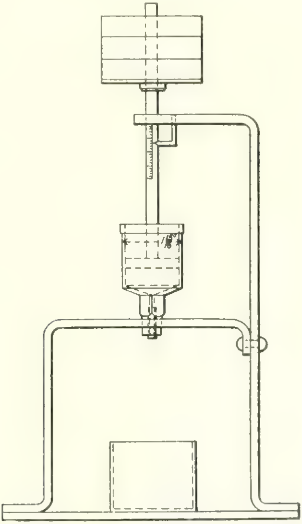

Fig. 40. Viscosity Apparatus.

The results of a number of tests of grease with this instrument are given below.

DENSITY TEST, X GREASE, No. 1 DENSITY

The same grease sample was passed repeatedly through the nozzle. The weight on the plunger was 20 lb.; temperature of grease, 71 deg. F.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Seconds to descend 1 in.	3750	235	95	66.2	57.4	36	27.2	23	19	19	16	24	14

The time became nearly constant after eight passages; the mean of Nos. 9, 10, 11, 12, 13 is 18.2 seconds.

A second test was made several days later, on the same grease sample as the preceding; load on plunger, 20 lb.; temperature of grease, 68 to 72 deg. F.

No.	1	2	3	4	5	
Seconds to descend 1 in.	17	12.6	14.2	13.8	14	mean time of last four, 13.6

The load was changed to 10 lb. and continued on the same grease sample as above; temperature of grease, 62 to 65 deg. F.

No.	1	2	3	4	
Seconds to descend 1 in.	572	670	597	593	mean time, 608

DENSITY TEST, Y GREASE, No. 3 DENSITY

A sample of the grease was passed through the nozzle 18 successive times with weights of 20, 15 and 10 lb. The temperature of the grease was 82 deg. F. at the start, increasing to 92 deg. F. at the end.

Load, 20 Lb.

No.	1	2	3	4	5	6	7	
Seconds to descend 1 in.	50	17.4	13	3.4(?)	6.4	6.8	5.2	mean time of last three, 6.1

Load, 15 Lb.

No.	8	9	10	11	12	13	
Seconds to descend 1 in.	15.8	16	12	11.4	11.6	9.6	mean time of last four, 11.1

Load, 10 Lb.

No.	14	15	16	17	18
Seconds to descend 1 in.	159	131	129.6	97.8	95

DENSITY TEST, Y GREASE, NO. 1 DENSITY

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Load, lb.	10	5	5	5	5	5	5	5	4	4	3	3	3
Seconds to descend 1 in.	3.2	23.6	31	18	27.4	25	23.8	19.8	57	59.4	273	250	267

Tests numbers 2, 3, 4, and 5 were made on successive samples of grease taken from the can. Numbers 6 and 7 were repetitions of grease that had been passed once through. Similarly, 11 and 12 were new grease, while 13 was the second passage. It will be noted that for this very thin grease, no very great change occurs with successive repetitions of the test on the same sample. The time for number 6 is almost exactly the same as the mean of the preceding four.

The consistency of grease as shown by the experiments described above becomes nearly constant after several passages through the apparatus at a constant load; but it appears that when the load is changed, the grease again requires a number of passages before coming to a constant condition of consistency. It is interesting to note the great effect produced in the time of flow of the grease by a small change in the weight. Thus, in the last test, Y grease No. 1, the time was increased about 450 per cent by decreasing the load from four to three pounds.

CONCLUSIONS

Grease lubrication compares favorably with oil where the form of bearing is such as to favor the retention of the film of lubricant, and provision is made for an ample supply to the bearing. But, as shown by the experiments of series A, oil will give better results in a bearing which is short in proportion to its diameter.

Grease of soft consistency is a much better lubricant than the harder densities of the same grease. The advantage of the softer grease is especially marked at low temperatures such as usually obtain in a well lubricated bearing.

The best method of applying grease to a bearing is by a forced feed and a constant rate of flow. This agrees with the best practice in oil lubrication, where the bearing is flooded with oil, which passes to a filter and is then used over again. The drawback in case of grease, is the problem of cleaning it after it has passed once through the bearing, so that it could be used over again.

Grease cups with spring actuated plunger are designed to give a constant flow of grease. They are far from accomplishing this purpose, however. When such a cup is full of grease, the spring is compressed to its maximum amount and the pressure upon the grease is therefore much greater than when the cup is nearly empty. Provision is made to regulate the flow by means of a small cock placed in the outlet of the cup, but this needs adjustment as the cup empties and is apt to be neglected. If the setting is right when the cup is filled the bearing will be insufficiently supplied when it is partly emptied. The experiments upon grease consistency show what a great difference in flow is produced by a small change in the pressure upon the grease. A design of cup is desirable which will deliver the grease at a constant rate from the time it is filled until it is empty.

TESTS OF LUBRICATING OILS.

The results of these tests are given in Tables Nos. 19 to 26, and in graphical form in figs. 41 to 48.

Eight oils, numbered 1 to 8, were tested. Their physical characteristics are given in the following table.

Number	Kind of Oil	Gravity, deg. Be.	Flash Point, deg. F.	Burning Point, deg. F.	
1	Liquid base cylinder oil	27	366	378	Yellow-green.
2	Engine oil	32	405	.. ..	Light red.
3	Standard gas engine oil	25.7	419	445	Dark red.
4	Gas engine oil	28.4	386	405	Light straw
5	Gas engine oil	20.9	340	350	Dark straw.
6	Engine oil.	20	348	362	Dark yellow
7	Gas engine oil	18.9	365	380	Straw
8	Engine oil	19.4	395	405	Reddish yellow.

TABLE NO. 19.

OIL NO. 1. LIQUID BASE CYLINDER OIL. (Fig. 41.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	81	102	121	141	159
65.6	.0196	.0143	.0086	.0068	.0049
103.1	.0155	.0095	.0065	.0037	.0030
135.7	.0126	.0060	.0039	.0047	0030
170.7	.0101	.0060	.0039	0037	.0029
204.7	.0080	.0059	.0044	.0041	.0036
239.8	.0066	.0056	.0051	.0060	.0042

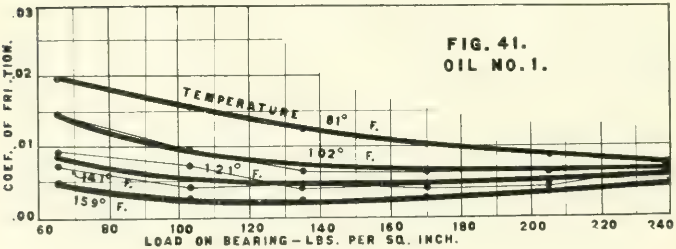

FIG. 41.
OIL NO. 1.

TABLE NO. 20.

OIL NO. 2. ENGINE OIL. (Fig. 42.)

Load on Bearing. Pounds per Square Inch.	Coefficient of Friction.			
	Temperature of Bearing. °F.			
	78	100	120	142
65.6	.0235	.0191	.0125	.0083
103.1	.0183	.0175	.0110	.0073
135.7	.0149	.0116	.0084	.0059
170.7	.0128	.0091	.0055	.0059
204.7	.0111	.0075	.0056	.0052
239.8	.0072	.0071	.0045	.0043

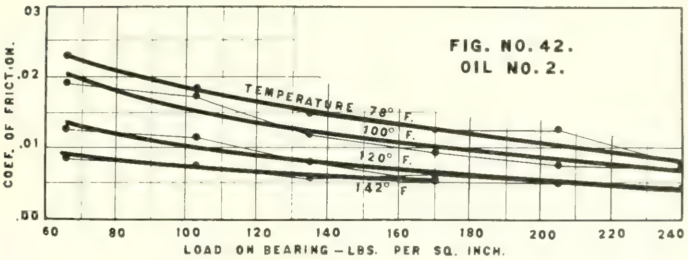

TABLE NO. 21.

OIL No. 3. GAS ENGINE OIL. (Fig. 43.)

Load on Bearing Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	80	101	121	140	160
65.6	.0424	.0270	.0165	.0153	.0093
103.1	.0300	.0205	.0125	.0124	.0058
135.7	.0232	.0168	.0125	.0075	.0058
170.7	.0198	.0158	.0115	.0066	.0057
204.7	.0165	.0140	.0089	.0056	.0055
239.8	.0139	.0127	.0087	.0066	.0056

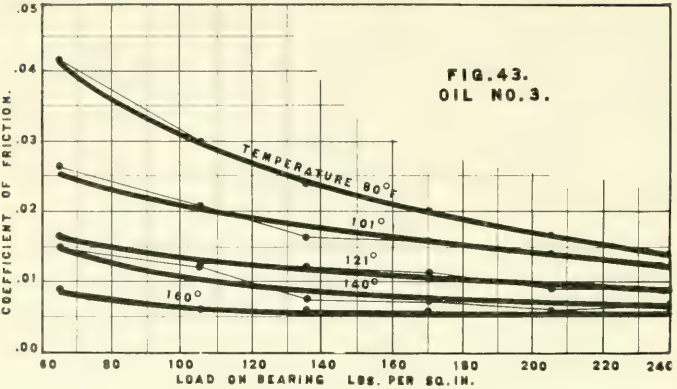

TABLE NO. 22.

OIL No. 4. GAS ENGINE OIL. (Fig. 44.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	79	103	121	141	159
65.6	.0271	.0152	.0174	.0075	.0056
103.1	.0186	.0162	.0103	.0025	.0057
135.7	.0167	.0105	.0088	.0056	.0039
170.7	.0140	.0087	.0082	.0052	.0034
204.7	.0115	.0089	.0067	.0041	.0036
239.8	.0095	.0080	0051	.0040	.0044

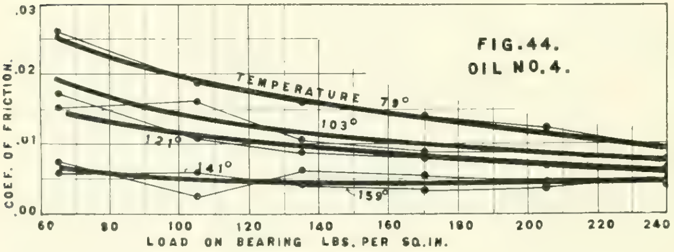

TABLE NO. 23.

OIL No. 5. GAS ENGINE OIL. (Fig. 45.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	79	102	120	141	160
65.6	.0319	.0197	.0110	.0140	.0059
103.1	.0319	.0155	.0092	.0125	.0050
135.7	.0238	.0115	.0072	.0062	0040
170.7	.0184	.0087	.0060	.0057	.0037
204.7	.0136	.0080	.0065	.0058	0033
239.8	.0121	.0062	.0077	.0057	0024

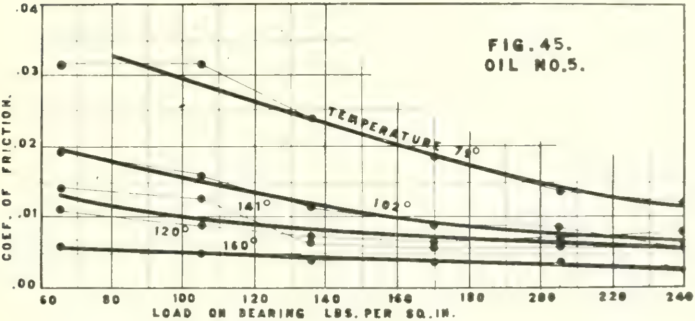
FIG. 45.
OIL NO. 5.

TABLE NO. 24.

OIL No. 6. ENGINE OIL (Fig. 46.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.			
	Temperature of Bearing, °F.			
	81	102	121	142
65.6	.0492	.0250	.0206	0088
103.1	.0283	.0211	.0133	.0063
135.7	.0272	.0172	.0135	.0064
170.7	.0200	.0132	.0092	.0063
204.7	.0158	.0138	.0087	.0057
239.8	.0148	.0107	.0090	.0051

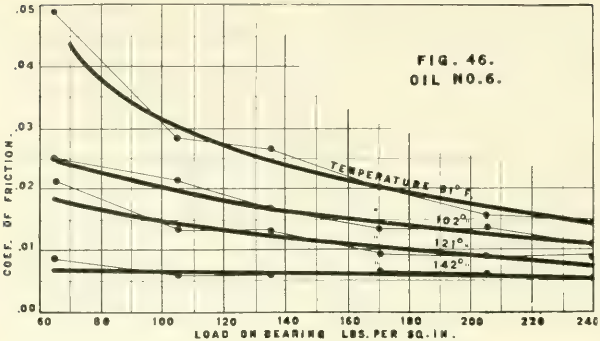

TABLE NO. 25.

OIL No. 7. GAS ENGINE OIL. (Fig. 47.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.				
	Temperature of Bearing, °F.				
	84	103	121	141	161
65 6	.0589	.0376	.0302	.0177	.0139
103.1	.0421	.0252	.0169	.0138	.0097
135.7	.0325	.0187	0150	.0119	.0064
170.7	.0135	.0154	.0137	.0097	.0062
204.7		.0131	.0128	.0084	.0065
239.8		.0124	.0110	.0071	.0070

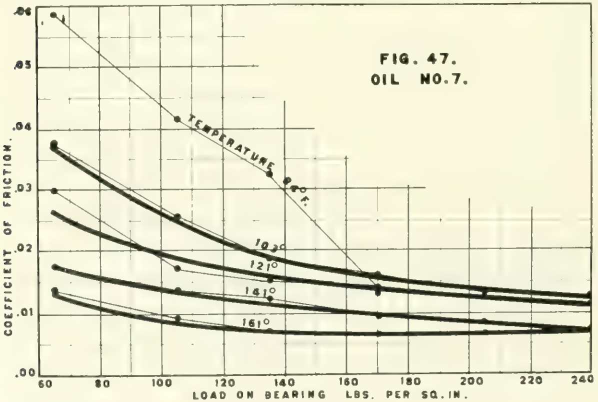

TABLE NO. 26.

OIL No. 8. ENGINE OIL. (Fig. 48.)

Load on Bearing, Pounds per Square Inch.	Coefficient of Friction.			
	Temperature of Bearing, °F.			
	85	102	120	141
65.6	.0706	.0463	.0306	.0183
103.1	.0427	.0345	.0217	.0136
135.7	0363	.0266	.0146	.0103
170.7	.0294	.0289	.0113	.0111
204.7	0253	.0213	.0112	.0093
239.8		.0180	0100	.0089

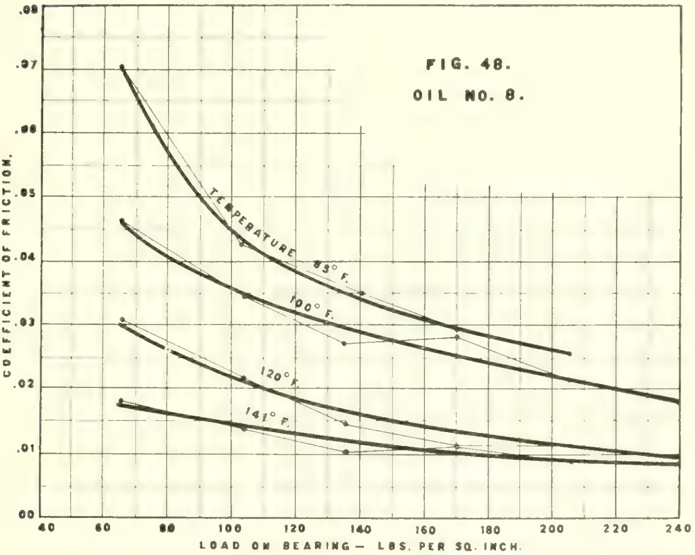

FIG. 48.

OIL NO. 8.

An inspection of the curves, figs. 41 to 48, shows that in general, the coefficients of friction vary directly as the specific gravities; the higher the gravity number, in degrees Baume, the less the coefficient of friction for a given load and temperature. This is especially marked in case of oils Nos. 6, 7, and 8, whose densities are not over 20 degrees Be. They give much higher friction values than any of the other, less dense, oils.

The forms of the curves showing the relation between load on the bearing and the coefficient of friction, are similar to those representing the grease tests. With increasing loads, the curves representing different temperatures tend to converge to a common point; and if the loading of the journal had been carried far enough, a point would have been reached where the curves for the higher temperatures would cross those representing the lower temperatures. A tendency in this direction is especially noticeable in case of oil No. 1.

In conclusion it may be stated that the friction test, as a guide to the selection of the best oil for a given purpose, and the elimination of the inferior oils, is not commonly employed. Experimental research by means of friction testing machines is recognized as of value for the purpose of developing the laws of friction of lubricated surfaces, and for making comparisons of the behavior of different lubricants under the same conditions. But there seems to be considerable doubt in the minds of lubrication engineers as to the value of such work as a means of determining the lubricating value of an oil in actual use. There can of course be no question but that the conditions of the test journal are ideal and quite different, as a rule, from those that obtain in a bearing in practice. The writer is of the opinion, however, that if a sufficient study were made of the question, a standard method of testing, in which the load, speed, quantity of lubricant applied, temperature, and length of time, are all carefully specified, might be devised and be of much practical assistance as an auxiliary to the other physical and chemical tests that are now commonly employed in the examination of lubricating oils.

An engine oil specification is given below, under which engine oil for general purposes is purchased by the St. Louis Water Works. This engine oil must be suitable for crank case oil, in engines having a splash system of lubrication, as well as for lubrication of the main bearings of engines and other general purposes. The qualifications laid down in the first paragraph, as to emulsifiable matter, etc., are therefore of the first importance. The oil must not emulsify when it becomes mixed with water in the crank case of an engine; and a special laboratory examination is necessary to see that the oil supplied possesses this qualification.

SPECIFICATIONS FOR ENGINE OIL NO. 1.

Engine Oil No. 1 shall be the filtered product obtained from the refinement of pure mineral crude oil without the subsequent addition of any other substance foreign to this distillation. It must be absolutely clear, free from water, tarry, emulsifiable or suspended matter and shall be absolutely neutral in its reaction.

The oil shall possess the following characteristics:

1. Its specific gravity shall not be less than 25.5 and not more than 26 degrees Be. at 60 degrees F.
2. It must not flash below 370 degrees F. when tested in Pensky-Martin closed flash apparatus.
3. It must not burn below 440 degrees F. in the open cup of the Pensky-Martin apparatus.
4. Its specific viscosity shall not be less than 12 degrees Engler at 70 degrees F.
5. When heated for seven hours at 150 degrees F. it shall show a loss of not more than 1% by weight; and when heated for two hours at 350 degrees F. it shall show a loss of not more than 14% by weight. There shall be no deposit of carbonaceous matter resulting from either of these tests.